

FINAL COMMENTS SUMMARY REPORT

External Letter Peer Review of Technical Support Document: Social Cost of Greenhouse Gas

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Contract No. EP-C-17-023
Task Order 68HERH22F0123

Prepared for:

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May 4, 2023

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I. INTRODUCTION

A robust and scientifically founded assessment of the positive and negative impacts that an action can be expected to have on society provides important insights into the policy-making process. One specific input to EPA analyses – the social cost of greenhouse gases (SC-GHG) – combines climate science and economics to put the effects of climate change into monetary terms to help EPA and the public understand the societal consequences of actions that would increase or decrease greenhouse gas emissions. The SC-GHG is the monetary value of the net harm to society associated with adding a small amount of that GHG to the atmosphere in a given year. In principle, it includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG, therefore, also reflects the societal value of reducing emissions of the gas in question by one metric ton and is the theoretically appropriate value to use in conducting benefit-cost analyses of policies that affect GHG emissions. EPA and other Federal agencies began regularly incorporating SC-GHG estimates in their benefit-cost analyses conducted under Executive Order (E.O.) 12866¹ since 2008, following a Ninth Circuit Court of Appeals remand of a rule for failing to monetize the benefits of reducing CO₂ emissions.

In 2017, the National Academies of Sciences, Engineering, and Medicine published a report that provides a roadmap for how to update SC-GHG estimates used in Federal analyses going forward to ensure that they reflect advances in the scientific literature (National Academies 2017). The National Academies' report recommended specific criteria for future SC-GHG updates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process. The research community has made considerable progress in developing new data and methods that help to advance various components of the SC-GHG estimation process in response to the National Academies' near-term recommendations.

In a first-day executive order (E.O. 13990), *Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis*, President Biden called for a renewed focus on updating estimates of the social cost of greenhouse gases (SC-GHG) to reflect the latest science, noting that “it is essential that agencies capture the full benefits of reducing greenhouse gas emissions as accurately as possible.” Important steps have been taken to begin to fulfill this directive of E.O. 13990. In February 2021, the Interagency Working Group on the SC-GHG (IWG) released a technical support document (TSD) that provided a set of IWG recommended SC-GHG estimates while work on a more comprehensive update is underway to reflect recent scientific advances relevant to SC-GHG estimation (IWG 2021).²

¹ Benefit-cost analyses have been an integral part of executive branch rulemaking for decades. Presidents since the 1970s have issued executive orders requiring agencies to conduct analysis of the economic consequences of regulations as part of the rulemaking development process. E.O. 12866, released in 1993 and still in effect today, requires that for all economically significant regulatory actions, an agency provide an assessment of the potential costs and benefits of the regulatory action, and that this assessment include a quantification of benefits and costs to the extent feasible. Many statutes also require agencies to conduct at least some of the same analyses required under E.O. 12866, such as the Energy Policy and Conservation Act which mandates the setting of fuel economy regulations.

² The SC-GHG estimates presented in the February 2021 TSD are reported in 2020 dollars but are otherwise

The EPA has applied the IWG’s recommended interim SC-GHG estimates in the Agency’s regulatory benefit-cost analyses published since the release of the February 2021 TSD. In addition, in the regulatory impact analysis of EPA’s November 2022 supplemental proposal for oil and gas standards, the Agency included a sensitivity analysis of the climate benefits of the proposed rule using SC-GHG estimates from a new, EPA draft technical report, “Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances.” This draft report presents a set of updated SC-GHG estimates that aims to incorporate the recent advances in the climate science and economics literature for use in the Agency’s analyses. Specifically, the draft report incorporates new literature and research consistent with the near-term National Academies’ recommendations on socioeconomic and emissions inputs, climate modeling components, discounting approaches, and treatment of uncertainty, and an enhanced representation of how physical impacts of climate change translate to economic damages in the modeling framework based on the best and readily adaptable damage functions available in the peer reviewed literature.

EPA requests independent expert review of this draft technical report that explains the methodology underlying the new set of estimates. This peer review is designed to be consistent with EPA’s Peer Review Handbook 4th Edition, 2015.³ The reviewers are asked to respond to each of the questions in each section below consistent with the reviewer’s experience and areas of expertise. EPA is primarily interested in the reviewers’ views on how well the methodological decisions draw on the best available research to fulfill the National Academies’ near-term updating recommendations. Separately, the Agency is also interested in the reviewers’ longer-term recommendations for further improving SC-GHG estimation in future updates. EPA will use the results of this peer review both to improve the utility, transparency, and accessibility of this near-term update as well as to inform our continuing efforts to update the scientific basis of the SC-GHG estimates used in EPA analyses.

identical to those presented in the previous version of the TSD and its Addendum, released in August 2016 (IWG 2016a, 2016b), which relied on methodologies and inputs developed in 2010 and 2013. As discussed in the February 2021 TSD, the IWG concluded that these interim estimates reflected the immediate need to have SC-GHG estimates available for agencies to use in regulatory benefit-cost analyses and other applications that were developed using a transparent process, peer reviewed methodologies, and the science available at the time of that process.

³ This peer review is being managed by a contractor to EPA, Versar. Versar reviewed the public nominations received in response to a 21-day call for peer reviewer nominations that ended on February 15, 2022 [federalregister.gov/d/2022-01387] to ensure they have the types of disciplinary expertise listed in the notice and used traditional techniques (*e.g.*, a literature search) to identify additional qualified candidates in the disciplines described below. Versar then developed a list of 14 candidate reviewers, collected public comments on the candidates, and used the comments received to select up the final panel of experts in a manner consistent with EPA’s Peer Review Handbook 4th Edition, 2015 (EPA/100/B-15/001), based on the following factors: (1) Demonstrated expertise through relevant peer-reviewed publications in one or more of the following areas: environmental economics, climate science, integrated assessment modeling, and benefit-cost analysis; (2) professional accomplishments and recognition by professional societies; (3) demonstrated ability to work constructively and effectively in a committee setting; (4) absence of conflicts of interest; (5) no appearance of partiality; (6) willingness to commit adequate time for a thorough review of the draft report, including preparation of individual written comments that will be made publicly available; and (7) availability to participate virtually in a public peer review meeting and to provide subsequent revised individual comments. Versar has independently conducted a conflict of interest (COI) screening of the candidates and final selected reviewers to confirm that those listed have no COI in conducting this review. Versar has ensured that the peer reviewers have not participated in the development of the product being reviewed and are independent of EPA as required under OMB’s Final Information Quality Guidelines for Peer Review (p. 38)

If helpful to their review, the reviewers may also consult the replication instructions and computer code for the estimates which are publicly available on EPA's website and any public comments on the draft report.⁴

Summary of Peer Reviewer Selection

On November 11, 2022, EPA announced in the Federal Register the release of the draft Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances for the purposes of public comment and peer review

(https://www.epa.gov/system/files/documents/2022-11/epa_scghg_report_draft_0.pdf).

Consistent with guidelines for the peer review of highly influential scientific assessments, Versar, Inc., an EPA contractor, was tasked with assembling five to seven scientific experts to evaluate the draft documents.

The peer review selection process was initiated with a three-week public nomination period held from January 25 to February 15, 2022, as documented in the Federal Register ([federalregister.gov/d/2022-01387](https://www.federalregister.gov/d/2022-01387)).

During this period, members of the public were able to nominate scientific experts with knowledge and experience in one or more of the following areas: (1) Environmental economics with a focus on modeling the impacts of climate change, uncertainty, and/or discounting, (2) climate science, with a focus on the estimation of future climatic variables resulting from different emission scenarios, and on the calculation of impacts resulting from elevated greenhouse gas concentrations, (3) integrated assessment modeling, and (4) benefit-cost analysis. Concurrently, Versar conducted an independent search for qualified scientific experts to augment the list of publicly nominated candidates. In total, Versar evaluated 60 candidates.

Versar screened the candidates against the selection criteria described in the Federal Register dated January 25, 2022 (<https://www.govinfo.gov/content/pkg/FR-2022-01-25/pdf/2022-01387.pdf>), which included: (1) having demonstrated expertise in the areas described above, based on information in their submitted resume, biographical sketch and/or current publications, (2) being free of any conflict of interest (COI) and the appearance of the lack of impartiality, and (3) being available to participate in two peer review meetings in the January and March timeframe. Following the screening process, Versar narrowed the list of potential reviewers to 15 candidates (nine nominated by the public and six identified by Versar) and provided the names of these candidates to EPA. A change occurred in the COI status with one of the original fifteen (15) reviewers, however, the remaining pool of candidates had sufficient depth and breadth of expertise for the review to move forward. Additionally, information on the 14 candidates, including their professional affiliations, expertise, education, and professional experience were provided and published on the EPA's designated website on November 11, 2022 (<https://www.epa.gov/environmental-economics/scghg-tsd-peer-review>). EPA's website also requested the public to submit relevant information or documentation on the list of candidates that Versar should consider during the evaluation process of selecting the final five to seven reviewers. Ten public comments were received during the three-week public comment period (November 11, 2022 to December 1, 2022).

⁴ EPA will help expedite transfer of public comments to the peer reviewers via the contractor, Versar, as they are received by EPA during the course of this peer review.

In selecting the final peer reviewers, Versar re-evaluated each interim candidate's credentials to select the experts who, (1) collectively, best covered the areas of expertise needed for this peer review, (2) had no real or apparent COI or appearance of the lack of impartiality, (3) were available to attend scheduled webinars, and (4) to the extent feasible, best provided a balance of perspectives. Versar reviewed the ten public comments received on the list of candidate reviewers. The most substantive comments focused on the strength of the candidates and that the final selections must include strong climate scientists along with representation of environmental economics. As a result, Versar also placed emphasis in considering reviewers with strengths in these areas.

After rigorous review and consideration of the available information, Versar selected the final seven peer reviewers.

Peer Reviewers:

Maureen Cropper, PhD
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Karen Fisher-Vanden, PhD
Pennsylvania State University

Chris E. Forest, PhD
Pennsylvania State University

Catherine Louise Kling, PhD
Cornell University

Michael Oppenheimer, PhD
Princeton University

Wolfram Schlenker, PhD
Columbia University

Gernot Wagner, PhD
Columbia University

II. CHARGE TO PEER REVIEWERS

1. Use of a modular approach to the methodological updates

Consistent with the National Academies' near-term recommendations, EPA separately updates the methodology in each step of the SC-GHG estimation—socioeconomic and emissions projections, climate science, economic damages, and discounting— increasing transparency and ease of updating each component to reflect the latest expertise from the scientific disciplines relevant to that component. Using this modular approach, EPA updated each step in SC-GHG estimation to improve consistency with the current state of scientific knowledge, enhance transparency, and allow for a more explicit representation of uncertainty.

- a. Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?
- b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?
- c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.
- d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?

2. Socioeconomic and emissions module

The socioeconomic and emissions module used in the draft report relies on a new set of socioeconomic and emissions projections developed under the Resources for the Future Social Cost of Carbon Initiative (collectively referred to as the RFF-SPs) (Rennert et al. 2022a). The RFF-SPs are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO₂, CH₄, and N₂O) to 2300 that were generated using statistical and structured expert judgement methods and accounting for future policies and interdependencies. The country-level population projections extend the fully probabilistic statistical approach used by the United Nations for official population forecasts, while incorporating improvements recommended by a panel of expert demographers (Raftery and Ševčíková 2021). The country-level empirical economic growth projections (Müller, Stock, Watson 2020) were extended in time using expert elicitation (Rennert et al. 2022a). The emissions projections are conditioned on future economic growth and a reflection of an “Evolving Policies” case (Rennert et al. 2022a).

- a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?
- b. Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages of these approaches.
- c. Do you have recommendations for improving the clarity and accessibility of the updated

socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?

- d. Do you have longer-term recommendations for improvements to this module in future updates?

3. Climate module

EPA's goal for this update of the climate module was to adopt a widely used, transparent climate model that could reflect the latest scientific understanding of the relationships between CO₂ emissions, atmospheric CO₂ concentrations, and global mean surface temperature change (and any other climatic variables required as inputs to the damage module) over time while accounting for non-CO₂ forcing and allowing for the evaluation of uncertainty. The climate module used in the draft report relies on the open source and widely used Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature change. The estimates presented in the report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b), in which the uncertain parameters have been calibrated to be consistent with the most recent assessment of the IPCC, such as the IPCC AR6 assessed likely range of 2.5 to 4°C for the equilibrium climate sensitivity.

- a. Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?
- b. Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.
- c. Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.
- d. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?
- e. Do you have longer-term recommendations for improvements to this module in future updates?

4. Damages module

Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. EPA's goal for this module is to evaluate the large increase in research on climate impacts and damages in the time since the models

underlying the IWG methodology to date were published. The damages module in this draft report relies on three damage functions to synthesize the existing literature. They are:

- a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),
- a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF’s Social Cost of Carbon Initiative (Rennert et al. 2022b)), and
- a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).

Each of the three damage functions is separately estimated in combination with the socioeconomics, climate, and discounting modules. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods. GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE and DSCIM are not included in Howard and Sterner’s (2017) final sample of studies. In Section 4.1 of the draft report, EPA combines the multiple lines of evidence on damages by averaging the results across the three damage module specifications to present SC-GHG estimates for a given range of discount rates.

- a. Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?
- b. Does the draft report’s use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes to you recommend? Do you think that there is a better approach for this update?
- c. For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.
- d. Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.
- e. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?
- f. Do you have longer-term recommendations for improvements to this module in future updates?

5. Discounting module

The discounting module used in the draft report relies on a set of calibrated dynamic discount rates. These rates were developed using a Ramsey discounting approach that endogenously

connects the discount rate and socioeconomic scenarios where the Ramsey formula parameters are empirically calibrated to match near-term consumption interest rates and reconcile long-run interest rate behavior and economic growth uncertainty consistent with the RFF-SPs. Uncertainty in the starting rate is addressed by using three near-term target rates – 1.5, 2.0, and 2.5% - based on multiple lines of evidence on observed interest rate data.

- a. Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?
- b. Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.
- c. Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.
- d. Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?
- e. Do you have longer term recommendations for improvements to this module in future updates?

6. Other

- a. Accounting for risk aversion:
 - i. Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?
 - ii. Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.
 - iii. Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?
 - iv. Do you have longer run recommendations for improved ways to account for risk aversion in future updates?
- b. Characterization of distributional impacts and other presentational recommendations for the draft report:
 - i. Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?

- ii. Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?
 - iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?
- c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities)?

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III. PEER REVIEWER COMMENTS BY CHARGE QUESTIONS

I. General Impressions	
REVIEWER	REVIEWER COMMENT
Cropper	<i>EPA's Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances</i> represents a huge advance in estimating the US Social Cost of Carbon (SCC). The estimates reported have successfully incorporated all of the short-term recommendations of the National Research Council (NRC) Committee on Valuing Climate Damages, and some of the longer-term recommendations. The report represents the state-of-the-art in executing the four steps of SCC calculation: (1) calculating probability distributions over future paths of population, GDP and emissions; (2) translating future emissions into future climate impacts; (3) estimating net damages associated with changes in climate; (4) discounting future damages to the present. The description in the report of these steps and how they were executed is excellent.
Cropper	While the current report admittedly does not cover all aspects of climate change (e.g., precipitation impacts and extreme weather events) and all categories of damages (e.g., the impacts of flooding) I believe that the information presented is accurate and that the conclusions reached are sound.
Fisher-Vanden	(NOTE: As requested by the USEPA at the second meeting, I have attempted to distinguish between comments that should be addressed in the current report ("SHORT-TERM") and comments that should be considered in a future report ("LONG-TERM"))
Fisher-Vanden	The approach taken to generate SC-GHG estimates is well-designed and executed and the document is well-written and easy to follow, although missing key details (as I describe below in my detailed comments). The modeling framework holds together well, and many choices made are defensible and based on current science.
Fisher-Vanden	Some larger issues I see, which are elaborated further below under specific sections, are: <ul style="list-style-type: none"> • (SHORT-TERM): A significant amount is left out of the analysis that could move the SC-GHG estimates in either direction. Throughout the report, the explanation that an approach satisfies the National Academy report's recommendation is used to justify methodological choices but is not very satisfactory. The report should be more transparent about the tradeoffs and how shortcomings of their methodological choices would bias the SC-GHG estimates. In particular, the analysis leaves out feedbacks, interactions, and other important considerations like intra- and international trade that will bias the results.

I. General Impressions	
REVIEWER	REVIEWER COMMENT
Fisher-Vanden	<ul style="list-style-type: none"> It is well-understood that far future damage estimates are very likely to be off and it is difficult to judge whether the right estimate would be higher or lower. It isn't all about growth uncertainty but ability to adapt and vulnerability in a richer world. The authors attempt to address this by having income influence the damage estimates, but this seems too simplistic since there will likely be constraints on populations' ability to adapt (e.g., island nations). The analysis also does not explicitly (but perhaps implicitly?) consider geoengineering options. Related, a world with climate change will be different and preferences will be very different as a result. (SHORT-TERM): It would be useful for the report to discuss what is explicitly and implicitly captured in this regard and how it would bias the estimates. (LONG-TERM): In a future report, it would be important to incorporate these omitted constraints into the estimates.
Fisher-Vanden	<ul style="list-style-type: none"> (LONG-TERM): Although I completely understand and appreciate the choice to go with a modular approach, it comes with trade-offs. The only models that can be swapped in are those that are structurally the same. This doesn't allow for innovation on the modeling side to capture feedbacks and processes better since they would encapsulate many steps in the causal chain.
Fisher-Vanden	<ul style="list-style-type: none"> (SHORT-TERM/LONG-TERM): In the spirit of transparency, I would recommend some discussion in the report on the process for updating these estimates going forward; in particular, a discussion about how new science and approaches (outside of the current approach) will be incorporated into future estimates, and how other research communities can participate in the process going forward. I noticed that some of the same people who participated in the National Academy recommendations were also those who generated these new SC-GHG estimates. Although what the authors have done here is scientifically sound, a different set of people may have taken a different approach. From the few public comments that I have read, there is a distinct feeling that certain people and communities who have expertise to offer were shut out of the process which would be important to address.
Fisher-Vanden	<ul style="list-style-type: none"> (SHORT-TERM): As elaborated below, a technical document that accompanies this report is needed so readers don't have to access, read, and knit together all of the cited documentation to fully understand what was done to generate these estimates.

I. General Impressions	
REVIEWER	REVIEWER COMMENT
Fisher-Vanden	<ul style="list-style-type: none"> • (SHORT-TERM): It might be useful to add a section that identifies important future research that is needed to improve the current estimates. This could provide a valuable research agenda for researchers in this field.
Forest	The update to the Social Cost of Greenhouse Gas Estimates is a significant step towards addressing the National Academies report in 2017 and continuing to improve the ability to assess the impact on the United States.
Forest	I am very happy to see the separate discussions on the four modular components provides sufficient material for the EPA to move forward and adopt the additional changes.
Forest	The new material and descriptions of updates in all modules include significant advances. The new materials have generally come from peer-reviewed research papers and the materials being provided by through both academic and research organizations addressing these critical issues.
Forest	I found the material to be very straight forward and easy to follow, despite the long footnotes, and recognize the differences between the academic research papers and the style of the EPA/government documents.
Forest	The use of itemized lists helps present the key updates such that readers can scan the document and easily identify the key findings in each section. This should be done in each section if possible. The use of key tables and figures are adequate to convey the content related to the primary updates.
Forest	As a committee member of the National Academies (2017) report, collectively, the new advances across all the subjects had significant updates.
Forest	The science and economics are continuing to mature, and the low-hanging fruit are few, while we're now picking from higher up in the trees. This continual upgrade and revisions process is an important component of this latest update to the Social Cost of Greenhouse Gas Estimates. The National Academies (2017) report provided questions to answer, and this report identifies where most of these have been answered.
Forest	To me, of the four components, the comprehensive update of the damage estimates is the newest part of the work and provides a major component that fits well with the other modules.
Forest	The update to the damage module will need to be reviewed and revisited once the final version is completed.

I. General Impressions	
REVIEWER	REVIEWER COMMENT
Kling	This is a much-needed improvement in estimating the social cost of carbon and greenhouse gas emissions. The Agency is to be applauded for taking leadership in developing this critically needed new set of estimates.
Kling	The document provides the basis for both an improved estimate to be used in rulemaking in the near term, as well as providing the core foundation for continuing refinements and improvements in the future.
Kling	While I have a range of questions and suggestions for improvement, it is important to recognize the significant step forward the agency has taken with this first set of estimates of the Social Cost of GHGs.
Kling	The overall structure of the report is clear and the development of the modular approach as recommended by NASEM is well articulated. By establishing a modular platform, the Agency is well positioned to both improve the current set of estimates and allow for updates over time as the scientific and economic basis for the estimates evolve and improve.
Kling	<p>Despite these strengths, there are shortcomings with the report in its current form. I begin with some overarching concerns and then address each of the charge question areas in more detail below.</p> <ol style="list-style-type: none"> 1. My first reaction to the writing style and content was that it was not detailed enough to be adequate for detailed technical review. After the helpful Zoom with EPA staff, I better understand the intended audience. The current level of depth suits their intended purpose well. However, a great deal of the analysis to support the module development and the empirical estimates generated are not sufficiently documented for careful review. Perhaps it would be useful to make clear in the intro that the document is intended as a road map, and that by necessity many of the details and decisions are documented in supporting materials and the interested reader should look there. Another possibility is to provide technical appendices.
Kling	<ol style="list-style-type: none"> 2. Definitions. The NASEM (2017) report was careful to define each term used throughout the report and to use them consistently. This report would be improved if it included a glossary of key terms. For example, the NASEM report defines the social cost of carbon as "...an economic metric intended to provide a comprehensive estimate of the net damages – the monetized value of the net impacts, both negative and positive – from the

I. General Impressions	
REVIEWER	REVIEWER COMMENT
	<p>global climate change that results from a small (1 metric ton) increase in carbon dioxide emissions,” (exec. summary p. 1). This report provides a similar, but not identical definition “the SC-GHG is the monetary value of the net harm to society from emitting a metric ton of that GHG to the atmosphere in a given year.” Beyond the obvious extension to all GHGs (which is great), this report’s definition does not clarify that the SC-GHG is metric intended to provide a comprehensive estimate. The fact that it is intended to do so but does not yet achieve that goal due to many omitted components, is important for transparency and for explaining updates in the future. In addition to providing a comprehensive estimate of impact damages, I suggest making clear in the definition that the metric include both future and current damages. Finally, the definition of the SC-CO2 as developed in this document differs from the definition of SCC in the NASEM report as this new social cost incorporates multiple GHG emissions, both through their effect on climate and through direct externalities (positive or negative) on ocean acidification, etc. I suggest highlighting these advances early in the document.</p>
Kling	<p>3. To be clear, the report does a good job in many places of describing that there are many important omissions from the current estimates of this metric, but this is an important enough of a point that it would be valuable to articulate clearly and early. I suggest that in the introduction, executive summary, and summary the EPA state more explicitly that current estimates of the metric do not meet the full bar of the intention, that however this is a major step to improve these estimates. I hope that doing so early will add to transparency so that when the next update is introduced with different numbers and more modules, the IWG or EPA can point to the current document as having laid out the foundation that such updates are expected and desirable, rather than appearing idiosyncratic or worse yet, politically motivated.</p> <p>Other useful definitions from the NASEM report include NASEM (2017) defined climate impacts as “the biophysical or social effects driven by climate change” and climate damages as the “monetized estimates of the social welfare effects” (p. 138 and elsewhere). Consistent use of terminology like this throughout would aid transparency.</p>
Kling	<p>4. In a number of places in the document the EPA reports that the estimates presented here are “conservative.” In some case this conservative (meaning lower bound?) estimate is explained as coming from omissions of information (like monetization of some damage</p>

I. General Impressions	
REVIEWER	REVIEWER COMMENT
	<p>impacts), in other cases, it is explained as an intentional effort to be conservative (also meaning to provide a lower bound?). The first issue is unavoidable and just needs more emphasis. I suggest explicitly using the words “lower bound” as “conservative” can have multiple meanings (e.g., if one were a proponent of the precautionary principle, conservative would mean use the highest damage estimate possible). The second issue is problematic for use of these metrics in benefit-cost analysis or any other economic efficiency interpretation. In general, if we are focusing on a single point in the SCC distribution for use in efficiency analysis, we should be trying to estimate the mean willingness to pay not percentile of the distribution that lies to the left. Inadequate attention to the economic welfare interpretations of the monetized damage components.</p>
Kling	<p>5. The report describes many places where the advice of NASEM (2017) was followed. That report was excellent and following their advice is great, but there are things that were suggested in that report that were not undertaken. A reader could easily believe otherwise (see Table 5.1 which lists the NASEM recommendations that were implemented but omits those that were not). For example, page 9 indicates that in the short run the IWG should, among other things update the damages by presenting spatially disaggregated market and nonmarket damages by region and second in both monetary and natural units (incremental and total) ... little to none of this has been done. As I argue below the omission of natural unit impacts is particularly concerning given how much remains nonmonetized. This point does not undermine any of the value of these new numbers, the point is to be transparent about what these numbers represent and what they do not.</p> <p>Equation 2.5.1 on page 62 provides something like this, but its variables are not defined (the use of Δ for “marginal damages” is confusing, is this defined in consumption of money?) and it does not discuss the aggregation component or the interpretation component.</p>
Oppenheimer	<p>The document Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances is, as far as this reader can discern, accurate in its representation of the current literature. The presentation is exceptionally clear and would be accessible to a knowledgeable non-expert working in the climate policy domain. The document’s conclusions are sound <i>within the self-constrained scope of its analysis</i>.</p>

I. General Impressions	
REVIEWER	REVIEWER COMMENT
Oppenheimer	However, the document does not go as far as it could in exploring the implications of ambiguities, sensitivities, and other characterizations of uncertainty.
Oppenheimer	In the long history of the climate change problem, it is this very arena, almost by definition, that has continued to provide surprising results and outcomes that force policy makers to update their approaches. For example, while the report does a good job of accounting for a range of plausible outcomes for ice sheet loss, it treats coastal adaptation “based on an optimistic assumption that optimal, lowest cost adaptation opportunities will be realized globally under perfect foresight about SLR.”
Oppenheimer	While the report does label this assumption as “optimistic”, it begs the question of why a pessimistic assumption wasn’t likewise deployed. In other cases, “many interactions and feedback effects are not yet represented, both in modeling physical earth system changes [e.g., feedback effects of tipping elements] and economic damages.”
Oppenheimer	Even though only one view of coastal adaptation and therefore only one end of a large range of possibilities is deployed for coastal damages, this may be better than the report’s other shortcoming: presenting no estimate at all for other features of the physical or social systems.
Oppenheimer	Simply put, the number of “Not Yet Incorporated” features in Table 3.2.1 is rather startling. Certainly, an approach more sophisticated than the 25% cost increment embedded in some of the modeling referred to but not deployed here could have been introduced, at least for some sectors/features of the system.
Oppenheimer	The rationale that the current approach allows the report to claim it uses “the most conservative damage function specification” will undoubtedly be challenged because some of the omitted features might, in fact, reduce damages, if (in my judgment) modestly.
Oppenheimer	Worse yet, “most conservative” is not very useful as a guide to policy if no quantification or qualitative expert judgment, even of low confidence, is attempted for such a large part of the scope of the problem.
Oppenheimer	Authors of this report may have been constrained by the limitation of consistency with the temperature-only estimates provided by the Climate Impact Lab, thus restricting the analysis to impacts that are easily represented as functions of temperature.
Oppenheimer	However, this approach could and should have been supplemented with additional modeling (e.g., semi-empirical, RCM’s) or estimation procedures (meta-analysis of existing literature, sensitivity testing) that would have permitted bounding of costs of other impacts.

I. General Impressions	
REVIEWER	REVIEWER COMMENT
Schlenker	EPA’s “Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances” outlines a revised methodology to derive the social cost of greenhouse gases.
Schlenker	I believe the report is well written: it provides a history of how the social cost of carbon was previously derived, a rationale for its revision, specifically how EPA is following the guidelines given by the National Academies of Sciences, Engineering, and Medicine (NASEM), as well as planned further revisions. I very much support the modular framework NASEM recommended, as it makes the individual steps in how the Social Cost of Greenhouse Gases (SC-GHG) is derived clear and allows people to modify individual components when new data becomes available or to test the sensitivity of the results to various parameters. Moreover, the analysis went away from the highly aggregated Integrated Assessment Models (IAM) that had previously been used and that did not incorporate the latest empirical findings.
Schlenker	<p>It should be noted that several comments were very complimentary for the work EPA had conducted.⁵ I concur – EPA is advancing our state of knowledge. There are specific suggestions for improvements I will discuss in more detail below, but I believe the proposed rule is an important step forward.</p> <p>⁵ Comment 2433: “[...] the Joint Environmental Commenters strongly support EPA’s supplemental proposal for new and existing sources [...]” Comment 2410 “[...] we strongly support EPA’s Supplemental Proposal.”</p>
Schlenker	<p>There are some comments whether the derived estimates are defensible.⁶ I do not share those concerns. While EPA acknowledges that there are uncertainties, simply not using any value because the analysis is uncertain does not avoid the problem but instead chooses a value of zero. Given the presented evidence, EPA’s revised values are clearly more defensible than a value of zero. A lot of evidence is given in the cited studies that changing weather patterns have an effect on societies.</p> <p>⁶ Comment 2339: “The SC-GHG estimates are highly speculative, policy-laden, and ultimately non-scientific.” Comment 2359: “Undetectable, non-experiential effects are ‘benefits’ in name only. Illusory benefits should not be weighed [...]”</p>
Wagner	The <i>Technical Support Document: Social Cost of Greenhouse Gas Estimates</i> represents a real step change in the formal calculation of the U.S. Social Cost of Carbon (SC-CO ₂), not least because of

I. General Impressions	
REVIEWER	REVIEWER COMMENT
	its explicit calculation of the Social Cost of Methane (SC-CH ₄) and Nitrous Oxide (SC-N ₂ O). It is generally well-written, technically sound, responsive to a host of comments and inputs (e.g. National Academy of Sciences 2017; Carleton and Greenstone 2021; Wagner et al. 2021) since the prior updates under the Obama administration (U.S. Government Interagency Working Group on Social Cost of Carbon 2015), and generally represents well the emerging consensus in the literature (e.g. Moore et al. 2023).
Wagner	<p>The ~\$200 ‘headline’ number (for a 2% discount rate) for each ton of CO₂ emitted today is well within the emerging scientific consensus of a significant body of work that shows climate change is indeed much more costly than the prior ‘interim’ ~\$50 number would suggest (e.g. Rennert et al. 2022; Moore et al. 2023; Bauer, Proistosescu, and Wagner 2023).¹</p> <p>¹ Amazingly, even Barrage and Nordhaus’s (2023) recent analysis agrees with this broad assessment. They do argue for an “optimal” carbon price of ~\$50/t CO₂. However, as they show in Figure 8, a discount rate of 2% would indeed come close to a \$200 SCC.</p>
Wagner	The 2% discount rate, too, is appropriately chosen to replace what the U.S. Government Interagency Working Group’s (2015) effort called the “central” 3% rate, with significant work pointing to using the lower 2% rate instead (e.g. Drupp et al. 2018; Council of Economic Advisors 2017; Greenstone and Stock 2021; Wagner et al. 2021). In fact, the proposed update to Circular A-4 argues convincingly for an even lower discount rate of 1.7% to be used in the short term (U.S. Office of Management and Budget (OMB) 2023).
Wagner	My one major recommendation is to improve the representation of climatic and climate-economic risks and uncertainties in the report, perhaps especially in the Executive Summary and the main Table ES.1 (see more below) but also throughout the report. The resulting SCC presented here can only be described as a ‘partial’ estimate, with a potentially long upper tail. That fact needs to be clear and consistently presented throughout the report.

II. Response to Charge Questions

Charge Question 1.

Charge Question 1.a. Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?

REVIEWER	REVIEWER COMMENT
Cropper	The use of a modular approach is a significant improvement over the bundling of DICE2013, PAGE and FUND. While each of these integrated assessment models (IAMs) has played an important role in enriching our understanding of the nature of climate change and policies to control it, the versions used to construct the interim SCC did not reflect the state of the art in climate science or in the modeling of climate damages.
Cropper	The advantage of the modular approach is that each of the four steps of SCC estimation can be executed by experts in the relevant area.
Fisher-Vanden	(LONG-TERM): Although making the modeling framework modular can, in principle, allow for the ability to “plug and play” any alternative socioeconomic, climate, or damage model based on new science, the reality is that the only models that can be swapped in are like-minded models that take in the same inputs and generate the same outputs. It doesn’t allow for new science on the <u>integration</u> of modeling components that can capture key feedbacks, dynamics, and interactions across submodels. The integrated assessment modeling community and the multisector dynamic community have a lot to offer in terms of new science in this area.
Fisher-Vanden	It should be noted that to capture feedbacks and interactions, it is not enough to just iterate across the four modules (socioeconomics, climate, damages, discounting) since this will not capture integrated impacts—the fact that impacts in one sector will affect impacts in another sector—e.g., sectors competing for the same scarce water.
Fisher-Vanden	This and the NASEM report both highlight the shortcomings of the previous IWG modeling approach as motivation for the approach that was taken in these new SC-GHG estimates. I don’t disagree with the points made in these reports. However, there are other integrated modeling approaches that could have been used and weren’t. There are obvious trade-offs between approaches, and it would be important to explain these trade-offs. From my read of it, the authors have given more weight to the importance of modularity (to allow for easy updates on the individual

Charge Question 1.a. Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?	
REVIEWER	REVIEWER COMMENT
	components) and improving the representation of uncertainty. In doing this, however, they are giving less weight to capturing feedbacks and interactions and providing sectoral and regional detail to understand distributional effects.
Fisher-Vanden	(SHORT-TERM): In this report, it would be important to discuss how these choices and omissions bias the SC-GHG estimates.
Forest	Yes, the modular approach works well, with the caveat that as finer scale information will eventually be added into more than one module and this will add another layer of complexity.
Forest	In the long run, new tools will be required to improve the sampling strategies across all modules to estimate the final distributions of the SC-GHG.
Kling	As noted above, the move to a modular approach is highly valuable and sets the stage for continuing improvements.
Kling	A suggestion for Figure 2.1 is to add a box coming from the damages module to represent unmonetized damages. Perhaps it would be “as yet unmonetized damages”? or something of that sort. Again, the goal is transparency and recognition of this omission.
Oppenheimer	The modular approach is certainly a major improvement over the previous approach because it increases transparency, avoids or makes more transparent many of the implicit and explicit expert judgments that the modeling underlying the previous approach obscured, and makes far easier the inclusion in the report of results from empirical modeling. The latter has in many ways revolutionized the study of many climate impacts as represented by a large and rapidly increasing literature. To not be able to include these results in a consistent manner would have undermined the credibility of this report.
Schlenker	The derivation of the SC-GHG has always required the four steps (modules) identified in Figure 2.1, however, earlier studies have often used simplifying assumptions on various parameters, e.g., picking an exogenous GDP or population growth rate, or implicit performed the three steps without breaking them apart. The modular approach has three major advantages: first, it clarifies the underlying assumptions and uncertainties of each step by dedicating a separate section it. Second, it allows for easy updating and revisions as new data become available – only the corresponding module will have to be adjusted. Finally, the sensitivity of the results to various modules is easily derived, e.g., several comments were with regard to the appropriate discount rate.

Charge Question 1.a. Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?

REVIEWER	REVIEWER COMMENT
Wagner	It does, and it does so well. The modular framework directly responds to calls from the U.S. National Academy of Sciences (2017) for just such a modular framework. The implementation builds on an impressive modeling effort spearheaded by Resources for the Future’s Social Cost of Carbon Initiative, culminating in the Greenhouse Gas Impact Value Estimator (GIVE) model (Rennert et al. 2022) and the ‘Mimi’ modeling platform created by David Anthoff, Richard Plevin, Cora Kingdon, and Lisa Rennels: mimiframe.org .

Charge Question 1.b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?

REVIEWER	REVIEWER COMMENT
Cropper	I think it is well described.
Fisher-Vanden	The report provides a very nice description and overview, but I found myself having to read a number of papers provided in citations or on websites to truly understand what was done and how the different pieces connected. For instance, how the RFF-SP socioeconomic projections were constructed and then fed into the damage models such as DSCIM was not explained well. From reading the DSCIM user manual, I now realize that the DSCIM estimates were based on SSPs and RCPs and in order to connect to the RFF-SPs, the authors were required to construct a weighted average of SSP projections to replicate a particular RFF-SP projection. Thus, it isn’t the case that the RFF-SPs are direct inputs to the DSCIM estimates. This was not clear in the report and is an important point since this approach could create consistency issues (as I discuss below in the damages module section). I wouldn’t have known this if I had not consulted other sources of information. (Note: It is unclear to me whether enough time was provided for the review panel to read and comprehend all of the necessary supporting documentation before commenting on the scientific soundness of some of these estimates).
Fisher-Vanden	(SHORT-TERM): Therefore, this report is excellent for providing an overview, but not appropriate for trying to understand and comment on what is going on under the hood. A much more detailed technical document, similar to the DSCIM user manual, for instance, should accompany this report.
Forest	Yes, the modular approach is clear for me. I have no specific recommendations at this time.

Charge Question 1.b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?	
REVIEWER	REVIEWER COMMENT
Oppenheimer	Yes, very clearly, and I have no specific recommendations with regard to the presentation. As indicated in my response to Question 1, I do have specific and general criticisms of the substantive approach, particularly regarding the treatment of uncertainty.
Kling	See above.
Schlenker	The modular approach is well described.
Wagner	Yes, and no. I also appreciate that the complete replication code is available via Github: github.com/USEPA/scghg

Charge Question 1.c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	(LONG-TERM): Similar to how this report used alternative damage function models, EPA could also offer SC-GHG estimates based on fully integrated modeling.
Fisher-Vanden	(SHORT-TERM): Even though the authors leave this as a ‘long-term goal’ in SC-GHG estimation, at a minimum, the authors should attempt to measure and discuss how leaving out the integration and feedbacks would bias the SC-GHG estimates since these current estimates will likely be used for many years.
Fisher-Vanden	(SHORT-TERM): It would also be useful for the report to explain how new science will be incorporated into future SC-GHG estimates. What will the process be for this? Will it rely on updates from the teams already in place?
Forest	To keep the modular paradigm/structure, I am advocating for more creative opportunities to incorporate climate/weather extremes into all modules when running an instance of the full model.
Forest	Each module has some connections to the climate data that drives emissions, the current observed climate pathways (given the uncertainty in projections based on historical records), and the impacts estimates.
Forest	I am not clear yet, on how the discounting might be connected to climate, but one relevant idea is that people’s preferences are psychologically connected to higher anxiety about the “current” climate trajectory. In turn, this would imply a stronger sense of urgency that would increase the value of the long-term future.

Charge Question 1.c. <i>Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.</i>	
REVIEWER	REVIEWER COMMENT
Forest	With a view towards sensitivity testing of the SC-GHG modules, I advocate to use stratified or direct sampling methods that allow accounting for the modules as well as the internal parameters within the modules.
Forest	Variants of Latin Hyper-Cube Sampling strategies (or similar tools) or methods of deep uncertainty quantification (e.g., Oddo et al. 2017, doi:10.1111/risa.12888) should be considered as model complexity increases.
Kling	No.
Oppenheimer	As noted above, the treatment of uncertainty is incomplete and could be improved. In particular, where physical science or adaptation science is incomplete, a one-ended (fuzzy) bounding exercise, as used for adaptation to coastal impacts, will not do.
Oppenheimer	There is really no excuse for not using available information to estimate some version of a low-probably “upper bound,” especially when high impact phenomena are at issue (like damage from intense precipitation events). This is old ground that has been covered and contested over and over and I find it surprising that this report retreated to what the authors probably considered to be safe ground, the so-called “conservative damage function specification.”
Oppenheimer	In fact, this report is inconsistent in using the range determined by deploying both FACT and BRICK for sea level rise while not using a similar approach for other features, which instead were simply elided.
Oppenheimer	Had this lacuna been thought about in advance, a bounding exercise for features other than sea level rise but analogous to the treatment in IPCC Sixth Assessment Report, WGI, Chapter 9.6.3.2 could have been developed in a timely fashion. At this time, it may or may not be too late to revise the approach to uncertainty, but this ought to be a top priority for the next cycle of SCC estimation.
Oppenheimer	An adequate representation of the right-hand tail is a critical feature for policy makers and aside from the bounds on outcomes implied by using both FACT and BRICK, this report fails to estimate tail risk, e.g., consequences of tipping points and other high-impact, low likelihood phenomena.
Schlenker	NASEM had short-term and long-term recommendations. I believe EPA has followed the recommendations it was given for short-term revisions. There are of course additional steps that can be done, as the report acknowledges, but EPA has done a remarkable step forward.
Wagner	There are not, and I’m saying that as the co-author of such “alternative” approaches. Daniel, Litterman, and Wagner (2018; 2019) and Bauer, Proistosescu, and Wagner (2023) present such an

Charge Question 1.c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.	
REVIEWER	REVIEWER COMMENT
	“alternative” approach of treating CO ₂ in the atmosphere as a “risky asset” with negative payoff. That approach results in an “optimal” CO ₂ price as the <i>output</i> of a benefit-cost analysis. It is no replacement for the calculation of climate damages used in the SC-CO ₂ , serving as an <i>input</i> into regulatory benefit-cost analyses.
Wagner	The same goes even more so for any efforts aimed at scrapping benefit-cost analyses altogether (Stern and Stiglitz 2021). It is true that other countries and jurisdictions rely less on benefit-cost analyses in setting domestic climate policy, and instead have passed laws that mandate (net) decarbonization by a date certain. Such approaches are crucial in regulatory environments where such net-zero laws are enshrined in law, and where regulatory analysis focuses on minimizing costs to achieve certain targets. That is not the case in the U.S. under most circumstances, once again pointing to the importance of calculating the SC-CO ₂ , SC-CH ₄ , and SC-N ₂ O as a crucial input into benefit-cost analyses (Aldy et al. 2021; Wagner 2021).

Charge Question 1.d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?	
REVIEWER	REVIEWER COMMENT
Cropper	In the longer term, as the NRC recommended, there need to be feedbacks among modules. If along a particular socioeconomic path there is a high probability of a negative climate outcome, and significant damages, this will reflect GDP along the path.
Fisher-Vanden	(LONG-TERM): Explore the generation of alternative estimates based on new fully integrated modeling efforts that are being done outside of the IWG efforts.
Forest	The only significant alternative would be to do a full Monte Carlo Sampling strategy with multiple millions of simulations. This would allow running an n=1000 or larger stratified sampling approach (or if computing is available, a full random sampling with n=10 ⁹) that could incorporate individual realistic futures to consider from high resolution Earth system models. This would lead to creating a 10+ year project to consider how to address the tails of the distribution.
Kling	See above.
Oppenheimer	See my answer to (c).
Schlenker	There is one potential downside to the modular approach: breaking the analysis into four subgroups might make feedback loops (shown in Figure 2.1) more challenging to implement as

Charge Question 1.d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?	
REVIEWER	REVIEWER COMMENT
	each module is developed in isolation and builds on a previous module. EPA acknowledges in Figure 2.3.1 that currently feedback loops are not included. The large uncertainty on future emissions paths is in part due to these feedback loops. The current approach is very much linear going from module 1 to module 4, but I would encourage EPA to incorporate feedback loops going forward, e.g., how is GDP growth impacted by climate change itself?
Schlenker	Will warming induce additional demand for cooling (ACs) that itself causes more emissions and amplify warming?
Wagner	There are indeed longer-term improvements the EPA could take, beginning with continuing to update damage functions to reflect the latest science—i.e. moving further damages from “unquantified quantifiables” into the quantified column (Proistosescu and Wagner 2020). (Table 3.1.4 shows some of the disaggregation. It also raises further question as to whether it is indeed appropriate to average across different damage modules, or whether some are better thought as being additive.)
Wagner	Then there are the many climate risks that either have not or cannot be quantified. Here, EPA needs to be clear whenever such an omission has occurred. The current EPA approach does a good job accounting for risks. However, more can and should be done, beginning with quantifying major climatic tipping points. The report cites Dietz et al. (2021); it does not incorporate the resulting numbers. (See charge question 4 below.)
Wagner	Further long-term improvements should look toward better representing climate damages affecting productivity and economic growth rates (e.g. Moore and Diaz 2015), explicitly factoring in “equity weights” (e.g. Anthoff and Emmerling 2018), and considering the importance of how further structural changes in risks and uncertainties affect the distribution of the SC-CO ₂ (Moore et al. 2023).

Charge Question 2.

Charge Question 2.a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?	
REVIEWER	REVIEWER COMMENT
Cropper	The RFF-SPs are a huge improvement over the five equally likely scenarios from the Energy Modeling Forum that constituted the SPs in previous estimates of the SCC. The RFF-SPs are based on econometric analysis (for GDP growth) combined with expert elicitation, using experts in each field. In most cases, the probability distributions for each SP span the values produced by the IPCC Shared Socioeconomic Pathways. This is a useful point of comparison, although the SSPs are not probabilistic.
Fisher-Vanden	The reasoning given for generating new scenarios using the methodology of the RFFSPs is related to the need to better represent the far future and to generate probabilistic long-run projections of population and economic growth, which was missing with the SSP/RCP scenarios. To address these needs, the RFF-SPs apply the Muller, Stock, and Watson (2022) approach which is based on convergence in economic growth theory to generate a set of probabilistic GDP projections. Therefore, my understanding is that future economic growth is driven by assumptions made about the speed of convergence of individual economies and their influence on the convergence of other economies with similar characteristics. The RFF-SPs then use expert elicitation (from a panel of macro growth economists) to extend the projections to 2300.
Fisher-Vanden	(LONG-TERM): Although this approach does address some of the important shortcomings of the IWG approach as identified in the NASEM report, it creates others that suggests a hybrid approach (e.g., one that combines growth projections with structural modeling) may be warranted:
Fisher-Vanden	(LONG-TERM): How do these RFF-SP projections ensure plausibility without some connection to structural models? That is, are the large structural changes that would have to occur in many lesser developed countries to reach convergence feasible? To assess this, you would need to know the structure and characteristics of the current economy and what structural changes would need to occur. In many instances, I presume, this may not be feasible based on fixed factors, technology, and other country-specific characteristics and endowments. In the construction of the SSP/RCP scenarios, structural economy-wide models helped identify and shape the set of scenarios by pointing out where certain pairings would not be possible—e.g. certain RCPs were not achievable with certain SSPs

Charge Questio 2.a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?	
REVIEWER	REVIEWER COMMENT
	without an infeasible set of technologies. We could be seeing a similar problem here with the use of these RFF-SPs.
Fisher-Vanden	(SHORT-TERM) : The report should discuss how the SC-GHG estimates would be different if trade was captured.
Fisher-Vanden	(LONG-TERM) : Importantly, the RFF-SP approach is not set up well for incorporating feedbacks from the damage modules and interactions across impacts. DSCIM, for instance, generates fine-scale dose-response functions by sector which could easily be incorporated into structural economy-wide models with spatial and sectoral detail. Not only would it allow for feedbacks, it would also allow for the explicit representation of integrated impacts, rather than modeling impacts separately for each sector. It isn't clear how this could be done with the RFF-SP model. As argued in the DSCIM description, it is important to estimate impacts at the fine scale and then aggregate up. Thus, it would also be important to capture feedbacks and interactions at the fine-scale and aggregate up.
Fisher-Vanden	(SHORT-TERM) : The report should include some discussion of how these feedbacks and interactions could be captured with the current approach.
Fisher-Vanden	(LONG-TERM) : Should the SC-GHG estimates capture distributional impacts somehow? If so, this doesn't seem possible with the current socioeconomic approach.
Fisher-Vanden	(SHORT-TERM) : The report should discuss whether this will be possible with the current approach and if so, how.
Fisher-Vanden	The RFF-SPs capture one type of uncertainty, from what I can tell. (I had to read Rennert et al, 2021 to understand this since the EPA Supplemental document does not provide details). They are capturing uncertainty by using expert elicitation where "experts provided their 1st, 5th, 50th, 95th, and 99th quantiles for the variables of interest: levels of OECD GDP per capita for 2050, 2100, 2200, and 2300" (Rennert et al, 2021) to "modify econometric projections of GDP per capita based on the MSW (2019) methodology and generate density functions of internally consistent projections of economic growth at the country level." Thus, the uncertainty captured is uncertainty related to speed of convergence (how far a country is from the frontier), I believe.
Fisher-Vanden	(LONG-TERM) : The current approach does not capture uncertainty related specifically to technological change, population growth, changes to the energy system, etc, or structural uncertainty

Charge Questio 2.a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?	
REVIEWER	REVIEWER COMMENT
	related to how factors/sectors interact. Rather it is implicit in an expert’s opinion on growth in GDP per capita in OECD countries. Again, this was an approach that was chosen by the authors that addresses some shortcoming from previous approaches but creates others. (How come the expert elicitation panel did not include experts involved in the SSP scenarios? These people have a lot to offer to this process).
Fisher-Vanden	(SHORT-TERM): The report should be more forthcoming on the types of uncertainty that are being captured and the types of uncertainty that are not, with a discussion of the magnitude and direction of the uncertainties that are left out.
Fisher-Vanden	(LONG-TERM): Therefore, an alternative approach may be to combine the growth modeling approach of MSW (used in the RFF-SPs) with the structural modeling, say, done by the IPCC economy-wide models (NOT the aggregate IWG models) in order to ensure that these economic growth projections are plausible and, to be clear to consumers of these estimates what these growth projections imply for the structure of individual countries in order to generate such growth projections. (This was a strength of the SSPs). This will be important for the damage estimates especially since some of these damage functions were estimated based on SSP/RCPs. It is also important for capturing interactions and feedbacks since economy-wide models are well-equipped to incorporate damage feedbacks.
Forest	I would offer the discussion from Sarofim et al. (2021, https://doi.org/10.1038/s41558-020-00973-9) that advocates for a hierarchy of modeling paradigms which fits the needs of the research question. Depending on the outcomes of the climate model projections, the users may want to account more carefully for non-linear outcomes for specific projections or impacts. Ultimately, this requires using models that include such non-linear equations. If the high-impact tails of a distribution are critical to the specific costs entering into the SC-GHGs, additional research will be needed to assess the uncertainties in the climate response and climate impacts.
Forest	The typical example from the climate science arena would be to ask: How close are we to any tipping points within the Earth system? If yes, then the non-linearities have a critical role to play to assess the level of impacts. The natural emissions of carbon dioxide, methane, and nitrous oxide still have a role to play as feedbacks driven by the anthropogenic forcings.

Charge Question 2.a. <i>Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?</i>	
REVIEWER	REVIEWER COMMENT
Kling	The work developed by RFF and used to produce the socioeconomic and emissions projection is a significant improvement and to follow the recommendations of NASEM (2017) well.
Oppenheimer	I'll pass on responding here as others involved in this review have greater expertise on this particular subject.
Schlenker	The report makes the underlying assumptions clear. There is a lot of uncertainty about future development, e.g., the confidence band on population forecasts by 2030 is very large. EPA does its best to incorporate this uncertainty in its analysis by following the statistical interpolation paired with expert solicitation that NCSEM recommended.
Wagner	Yes. It is the most comprehensive effort to date to update the socioeconomic pathways and represents an impressive undertaking, reflecting some of the latest insights around probabilistic growth projections (e.g. Christensen, Gillingham, and Nordhaus 2018).

Charge Question 2.b. <i>Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages of these approaches.</i>	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	(SHORT-TERM/LONG-TERM): For comparison, why not use the SSP/RCPs scenarios as was used by the DSCIM team to generate their damage estimates instead of the RFF-SPs to see what difference it would make in the SC-GHG estimates?
Forest	This is not my area of expertise.
Kling	None that I am aware of.
Oppenheimer	See response to part (a).
Schlenker	None in the short-term. I would encourage them to take feedback loops seriously for the long-term revisions (GDP growth is itself a function of climate change).
Wagner	n/a

Charge Question 2.c. Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	(SHORT-TERM): As mentioned prior, this is another instance of having to read a number of other papers in order to fully understand what was being done. Please supply a technical document to accompany the report.
Forest	For the emissions model, specifically, we know that the emissions and sinks of methane are strongly dependent on climate variables such as temperature and precipitation within the tropics and extratropics.
Forest	For methane, the destruction rate of methane is a key issue and should be included in the models.
Forest	While the heat-trapping gases will take multiple decades to impact temperature, the concentrations of nitrous oxide and methane can have immediate impact on air quality and thus, have direct impacts on human health and on local ecosystems when they are emitted. To better understand these impacts, we need to incorporate the secondary effects of the GHGs that contribute to the damage estimates, which could help clarify how these effects add to the Social Costs or to identify what processes could be missing.
Forest	While not explicitly having specific suggestions on the socioeconomic module, we know that climate change can have direct and indirect effects on the socioeconomic activities. From a communication perspective, we should develop storylines to explain both direct and indirect interactions of the socio-economic and emissions model with the other modules. Within the context of SC-GHG, we should use such storylines to help the public and the private sector improve communications and clarify many of the subtler issues as research continues to improve these tools. While we have a clearer understanding of how climate change is driven by emissions, we must also create clearer messages on how feedbacks from climate change are similarly driving changes in both socio-economic factors and emissions.
Kling	This is a place where more details would be useful, especially more details about how the future climate scenarios were informed and altered by expert judgment.
Kling	An important part of these projections is the advice from NASEM to take account of future emission policies and the consequences. Again, this is to be applauded, but documentation of how this was done, how big of an effect this component had should be discussed and documented.

Charge Question 2.c. Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?	
REVIEWER	REVIEWER COMMENT
Kling	Visually demonstrating how much of an effect on the emissions stream the judgements on policy responses and adaptations would improve the transparency of the report. If possible, it would also be valuable to document/explain how much difference incorporating these policies induced changes made in the computation of the social cost estimates.
Oppenheimer	See response to part (a).
Schlenker	The one comment I have on clarity is to better explain that the uncertainty bands include policy options. When people see the wide confidence bands by 2300, an intuitive response might be to discredit the model as unreliable given the large range of possible outcomes.
Schlenker	However, a big fraction of the “uncertainty” is due to policy choices, which aren’t modeling uncertainty – see next point. Treating each RFF-SP as equally likely might make it look as these are random possible outcomes of the future – but again, they are in large part choices.
Wagner	Same general comment here as elsewhere: It is key to do represent the nature of risks and uncertainty in a consistent fashion. One good way to doing so might be a consistent portrayal of probability density functions across different scenarios akin to Figure 2 in Rennert et al. (2022), Figure 2 in Dietz et al. (2021), and elsewhere.

Charge Question 2.d. Do you have longer-term recommendations for improvements to this module in future updates?	
REVIEWER	REVIEWER COMMENT
Cropper	As noted above, there should, ideally be feedbacks from the damages module to the socioeconomic pathways. This is something for future research.
Fisher-Vanden	See comments under a.
Forest	My long-term suggestions are most relevant for natural emissions being driven by the future climate changes that would add additional feedbacks on both climate impacts and on climate change itself. The ability to assess these feedbacks will be critical and then, we must feed the natural emissions into both the climate module and the impacts module as well would be useful.
Kling	See above.
Oppenheimer	See response to part (a).

Charge Question 2.d. Do you have longer-term recommendations for improvements to this module in future updates?	
REVIEWER	REVIEWER COMMENT
Schlenker	The report states “RFF-SPs explicitly account for the likelihood of future climate policies,” so part of the divergence in the observed emission pathways is hence due to public policy choices. I would separate the range of future emissions that is (i) due to modeling uncertainty, e.g., on population growth, from (ii) emissions changes that are due to climate policies. That makes it clearer what fraction we don’t know (modeling uncertainty) versus what are simple choices.
Wagner	A key longer-term improvement is an explicit treatment of adaptation to current and projected future climate damages. Doing so is difficult for a number of reasons, not least in understanding which way the sign goes. E.g. does adaptation in form of human migration count as a cost of unmitigated climate change, or does it lower costs? Even where the sign is clear, quantification is anything but simple. Yet it needs to be part of a comprehensive effort to account for the full costs of unmitigated climate change.
Wagner	A second such topic concerns internalizing the rapidly declining costs of carbon mitigation technologies (Gillingham and Stock 2018). These costs do not affect the EPA’s SC-CO ₂ as much as calculations of the “optimal” SC-CO ₂ , but they do still enter via socio-economic pathways. Consistency here is key, including e.g. with forecasts by the U.S. Energy Information Administration and other efforts (Wagner et al. 2021). Moreover, these projections are rapidly changing, not least due to major U.S. government investments in clean energy via the Inflation Reduction Act, the bipartisan infrastructure law, and the CHIPS and Science Act leading to learning-by-doing on a massive scale (e.g. Arkolakis and Walsh 2023; Wagner and Friedmann 2023).

Charge Question 3.

Charge Question 3.a. Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?

REVIEWER	REVIEWER COMMENT
Cropper	The FAiR model improves significantly upon the climate portions of DICE2013, FUND and PAGE. These IAMs do not reflect the latest climate science (e.g., Joos et al. 2013) which suggests that the maximum impact of a pulse of CO ₂ on mean global temperature will be felt within 20 years. (See also Figure A.5.7 in the Appendix.) The FAiR model was developed by members of the NRC committee in response to their criticisms of the climate portions of DICE, FUND and PAGE.
Fisher-Vanden	(LONG-TERM): It seems important for the climate module to capture precipitation and not just temperature, which is a shortcoming of the current approach. My understanding, though, is that this was done because the damage functions are only based on temperature and not precipitation which is a shortcoming of these damage functions.
Forest	Yes, this update provides an improved representation of the climate response to the net radiative forcing based on the accumulation of GHGs in the atmosphere and ocean.
Forest	The testing of the Reduced-complexity Climate (RC) models has been tested against IPCC-class Earth System Models. Developers of all three models (FAIR1.6.2, MAGICC7, and HECTOR2.5) are participating in the IPCC RCMIP (Nicholls, Z. R. J., et al., 2020, https://doi.org/10.5194/gmd-13-5175-2020).
Forest	The goals of the RCMIP project are to be able to assess the perturbation between the reference scenario and a perturbed scenario to determine the additional global warming associated with the perturbed forcing. This perturbation is fed into the climate impacts module to estimate the climate impact damages. Based on the RCMIP results, these three models have the necessary components to estimate the global mean temperature that can be used in the RC module.
Kling	This is outside my area of expertise.
Oppenheimer	While the climate module approach improves upon the previous framework, it falls short in producing only changes in temperature as the primary output (the motivation for which I note in General Impressions). This may be the primary reason that Table 3.2.1 has so many open circles.

Charge Question 3.a. <i>Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?</i>	
REVIEWER	REVIEWER COMMENT
Oppenheimer	Much as I recommend above that the treatment of uncertainty across many features of this analysis should be broadened, I likewise recommend that some additional features of the climate system, especially precipitation, be included in SCC uncertainty range.
Oppenheimer	While parameterization of global mean precipitation change as a function of temperature is often done, regional precipitation changes, which are what count for impacts, are not so easily estimated in this manner. Still, it might have been feasible to estimate an uncertainty range for regional precipitation changes. The strict adherence to FaIR’s output temperatures as the sole independent variable driving impacts seems to have inhibited creativity on this score. While it may be too late now to correct this problem, it surely should be atop the agenda for the next round of SCC estimation.
Schlenker	This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers.
Wagner	Yes, it does. Much work has gone into assessing climate uncertainty, oft focused on climate sensitivity uncertainty (Sherwood et al. 2020). The EPA report reflects the latest consensus assessment by the IPCC in AR6.
Charge Question 3.b. <i>Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.</i>	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	I defer to others on the review panel who are better equipped to comment on this.
Forest	Higher order complexity models are available and should be considered to benchmark the RC models. Despite the computational costs Notwithstanding can be prohibitive, we should be testing “state of the science” models now that improve our level of understanding for regional climate changes.
Kling	Again, outside of my expertise.

Charge Question 3.a. Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?	
REVIEWER	REVIEWER COMMENT
Oppenheimer	The following might be feasible: a limited number of simulations with a few ESMs (or several realizations of one ESM) that have shown some skill with regional precipitation could be run in order to develop upper and lower limits on regional precipitation change.
Schlenker	This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers.
Wagner	Sherwood et al. (2020) is indirectly cited via IPCC AR6. Given the importance of that prior assessment, I would suggest citing it here directly as well.

Charge Question 3.c. Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	I defer to others on the review panel who are better equipped to comment on this.
Forest	I am only familiar with the two sea-level models in this report at this time.
Kling	Not that I am aware of.
Oppenheimer	Given current ice sheet modeling limitations, the key consideration with regard to the physical science aspects is whether the approach used in this report provides uncertainty bounds that are consistent with AR6. Since this is the case, I have no additional recommendations on the approach to modeling physical sea level rise.
Oppenheimer	However, assuming your request's use of "impacts" in this question includes the ameliorating (or worsening) effects of adaption (maladaptation), see my comments under General Impressions on the inference of damages from the estimated range of rise. The assumption of optimal adaptation is absurd on its face given all evidence to the contrary for the US in particular. See a summary of my presentation to PCAST, October 18, 2021 at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjripOu68

Charge Question 3.c. <i>Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.</i>	
REVIEWER	REVIEWER COMMENT
	<p>z9AhUgFVvFHQzDD3wQFnoECAgQAQ&url=https%3A%2F%2Fwww.whitehouse.gov%2Fwp-content%2Fuploads%2F2021%2F12%2FMinutes_PCAST_Oct-18-19-2021_FINAL.pdf&usg=AOvVaw2V072hEMrr5EgbzvFxjekk</p> <p>Notably, Federal policy toward adaptation has improved since then but the institutional obstacles noted largely remain unaddressed.</p>
Schlenker	This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers.
Wagner	n/a [I defer to other peer reviewers' expertise here.]

Charge Question 3.d. <i>Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?</i>	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	I defer to others on the review panel who are better equipped to comment on this.
Forest	Based on the RCMIP work (Nicholls et al. 2020), I would consider figures to develop storylines of the trade-off between ocean carbon and heat uptake and the surface warming due to the GHGs. Additionally, we need to better describe uncertainties of the trade-offs between surface warming and net radiative forcing. These may be technical issues, but users might understand that if the ocean is not warming quickly, then the land/ocean surface must be warming faster.
Kling	It would be helpful to a nonexpert (like me) to understand the baseline on which to consider the 1 GtC pulse of carbon dioxide. Is that a .001% pulse or more like a 5% pulse?
Kling	Figure 3.2 contains a list of the set of climate impacts that are not currently captured in the climate module. It would be useful to discuss the consequences of those omissions for the computation of the social cost of GHG estimates. Given that these climate impacts are not represented in this work, what does that imply for the damage estimates that cannot be included in the SC GHG estimates (such as the impacts of ocean acidification as explained on page 35).

Charge Question 3.d. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?	
REVIEWER	REVIEWER COMMENT
Oppenheimer	See my previous comments.
Schlenker	The report states how “Reduced-complexity climate models [...] are computational emulators of the climate system.” Predicted climate change is highly non-uniform, with higher latitudes seeing more warming. The emulator captures this, but the report exclusively focuses on the mean temperature increase.
Schlenker	I would highlight more that these mean increases translate into non-uniform warming around the globe, with the US seeing above-average warming. This non-linear warming is then used in the next section on damages.
Wagner	Here as elsewhere, one note on representing risks and uncertainties: Tables 2.2.1 and 2.2.2 present the long right-tailed distribution for both equilibrium and transient climate sensitivity distribution. For consistency sake, it would be good to present the calibrations of the tables graphically in a way that is consistent across modules—akin to Figure 2 in Rennert et al. (2022), Figure 2 in Dietz et al. (2021), and elsewhere. Doing so would also highlight the right-skewed nature of the climate sensitivity distributions more so than a table can.
Wagner	This module also makes clear how the resulting SC-CO ₂ can only be described as a ‘partial’ estimate, given e.g. that precipitation impacts are (largely) excluded from the analysis. The report, in part, uses the term “conservative” when it means “lower bound” and/or “partial.” Calling the resulting SC-CO ₂ a “partial” estimate might also be important from a process perspective, establishing the fact that the calculations will inevitably be updated going forward.

Charge Question 3.e. Do you have longer-term recommendations for improvements to this module in future updates?	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	(LONG-TERM): This module must include precipitation and the damage functions must be able to take this important climate variable into account.

Charge Question 3.e. Do you have longer-term recommendations for improvements to this module in future updates?	
REVIEWER	REVIEWER COMMENT
Forest	The ability to sample the transient climate response and the sea level changes are the key elements in the current RC models until moving to more comprehensive models. I am concerned that “solar radiation reduction” could be a realistic scenario that might not be modeled well with the current modeling systems.
Kling	Continuing to focus on both physical and monetized impacts should continue to be prioritized in future updates.
Oppenheimer	A start has been made by several research groups around the world on realistic modeling of coastal adaptation. EPA ought to do better in the future than merely asserting “lower bound” to justify using a ridiculously optimistic assumption for coastal adaptation. Let’s try to get a plausible upper bound, too.
Schlenker	This outside my area of expertise and I defer to my colleagues on the committee that are climate modelers.
Wagner	n/a [I defer to other peer reviewers’ expertise here.]

Charge Question 4.

Charge Question 4.a. Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?	
REVIEWER	REVIEWER COMMENT
Cropper	The current damage modules represent a significant improvement over the damage functions in DICE, FUND and PAGE for two reasons: they are based on more recent studies than the studies underlying DICE 2013, FUND and PAGE, and the three damage modules represent independent sources of information. The damage function in DICE 2013, FUND and PAGE used in the previous SCC were not independent sources of information.
Cropper	The DSCIM estimates are based on extensive, original empirical work, at a fine spatial scale. The GIVE model relies on other well-regarded published studies. Howard and Sterner is a meta-analysis

Charge Question 4.a. Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?	
REVIEWER	REVIEWER COMMENT
	of both top-down and bottom-up damage studies. The use of all three sources of damages strengthens the results.
Fisher-Vanden	The damages module in this report is an improvement over the IWG methodology in that it captures updated science (and numerous new studies) on measuring and monetizing impacts including regional and sectoral disaggregation and coverage, and greater use of empirical evidence. However, these approaches have some drawbacks:
Fisher-Vanden	(LONG-TERM) : Sectoral damages do not feedback to the socioeconomic module, which will affect economic growth and thus emissions and ultimately damages. As argued in this section of the report, it is important to estimate impacts at the fine scale and then aggregate up. Thus, it would also be important to capture feedbacks and interactions at the fine-scale and aggregate up.
Fisher-Vanden	(SHORT-TERM) : The report should discuss how leaving out these feedbacks would bias the SC-GHG estimates.
Fisher-Vanden	(LONG-TERM) : All of the damage function approaches considered in both the IWG and this report estimate sectoral and regional damages separately and do not consider integrated impacts (the fact that impacts in one sector or region could influence impacts in another sector or region), indirect sectoral impacts, or trade implications which could alleviate or exacerbate these estimates.
Fisher-Vanden	(SHORT-TERM) : This report should include a discussion of how modeling sectoral impacts separately would bias the SC-GHG estimates.
Fisher-Vanden	Damage functions are functions of temperature and not other climate variables such as precipitation and extremes which are key to impacts. (LONG-TERM) : Future estimates should address this issue.
Fisher-Vanden	(SHORT-TERM) : This report should discuss how this omission would bias the SCGHG estimates.
Fisher-Vanden	Also potentially problematic is the lack of a direct connection between the RFF-SPs and damage functions. For instance, the DSCIM estimates were based on SSPs and RCPs and in order to connect to the RFF-SPs, the authors were required to construct a weighted average of SSP projections that most closely resemble each RFF-SP projection. Thus, it isn't the case that the RFF-SPs are direct inputs to the DSCIM estimates. I believe this could bias the damages results if there are nonlinearities in the inputs to the damage function since you are taking weighted averages of multiple SSPs that individually could be much different from each other.

Charge Question 4.a. Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?	
REVIEWER	REVIEWER COMMENT
Fisher-Vanden	(LONG-TERM): The socioeconomic or damage module should be revised so there is a direct connection. This highlights the potential issues that can arise with the modular approach—there needs to be consistency on the outputs and inputs between two connected modules.
Fisher-Vanden	(SHORT-TERM): The report should assess and discuss the implications of the weighted average scenarios approach taken for the damage estimates.
Fisher-Vanden	(LONG-TERM): Another reviewer on the panel made the excellent point that it is important to recognize and capture the fact that damages will affect utility through different channels. This point underscores the importance of structural modeling that can capture these different channels.
Fisher-Vanden	(SHORT-TERM): Therefore, this report is excellent for providing an overview, but not appropriate for trying to understand and comment on what is going on under the hood. A much more detailed technical document, similar to the DSCIM user manual, for instance, should accompany this report.
Forest	Yes, this update provides a better general estimate of the damages than a few functional representations in the original models. While these are more comprehensive, they are most likely to be underestimating damages if smaller sectors are left out.
Kling	I suggest EPA considering dropping the use of the term “sector” to describe components of damage and instead use their alternative term “impact category.” The term, “sector” in economics typically refers to an industry (agriculture, manufacturing, etc.) which is not what is being referenced here. Further, the broad terms of health, agriculture, suggest that the EPA has monetized and considered all impacts in that category, but in most/all cases, many impacts are currently omitted. For example, DSCIM incorporates only mortality under the “health sector.” The agricultural sector, etc. are also only partial.
Kling	Footnote 76 documents the source of the value of risk reduction (VSL) as being the dated 1990 estimate, updated for income growth. Numerous authors have called for these numbers to be updated for years. Their continued use may be understandably pragmatic for now but updating these numbers using improved methodology and data is long past due. I urge EPA to prioritize that effort.
Kling	It is unclear how summing 5 separate damage estimates relates to the underlying welfare theory. Specifically, each of the 5 damage estimates constructs a separate welfare measure that come from different revealed preference methods. In the case of mortality valuation, the use of a value of risk reduction construct to multiply by the expected change in mortality is theoretically consistent with

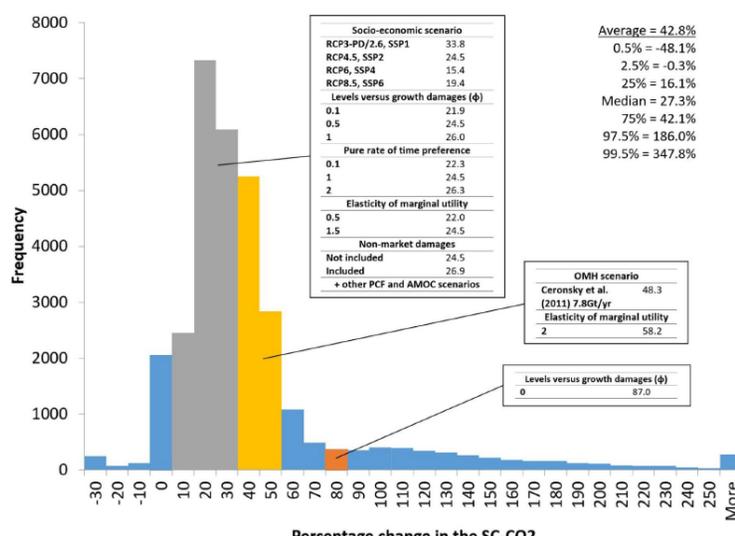
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REVIEWER	REVIEWER COMMENT
	the ex-ante welfare values that are appropriate. I am less clear how the energy component--- the change in energy expenditures --- is related to the <i>ex-ante</i> wtp to avoid uncomfortable temperatures. Since estimates of increased energy use to heat and run air conditioning is approach, it seems that the theoretical basis should come from the use of the revealed preference methods of defensive expenditure. In that case the literature on how to use defensive expenditures to estimate the bounds on theoretically correct wtp is necessary to make this linkage. Bartik developed a key result (also covered nicely in coverage in applied welfare economics textbooks (Bockstael and McConnell, Phaneuf and Requate, Freeman et al.)) that make clear these expenditures can only be viewed as lower bounds.
Kling	Given that the estimates in this report indicate a negative estimate for energy costs, and that number is nothing but a lower bound, that's a point that is important to make. I think similar questions can be asked about the other issues. This question is probably best thought of as a long run component of a research agenda rather than something necessary to address now.
Oppenheimer	Yes, see my comments in response to General Impressions and Question II.1.a. The inclusion of empirical modeling as an equal contributor to this assessment provides an important improvement. Of course, more work needs to be done to understand the ways the processes and empirical damage functions differ from the current method versus the earlier approach, especially with regard to their respective abilities to capture the effect of adaptation, if they do at all.
Oppenheimer	Furthermore, the out-of-sample question needs to be explored in great detail for particular impacts in order to assess the limitations of projection based on inference from empirical studies (see for example, the Wagner submission, Fig. 3A and related comments). This should be a project for future research.
Schlenker	The NASEM highlighted that the previous IAMs did not incorporate the latest scientific findings. The current analysis is a big step forward. I congratulate the EPA for its efforts to include three separate well-described approaches. These include both micro-level statistical studies as well as aggregate damage functions and a meta-analysis. I realize that meta-studies are common in the literature, but I am personally a bit hesitant to employ them as they place equal weight on each study when I believe some are more defensible than others.

Charge Question 4.a. <i>Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?</i>	
REVIEWER	REVIEWER COMMENT
Schlenker	As discussed below, the sectoral damages vary vastly by approach and it would be interesting to dive further into where the differences stem from going forward and go with the number that is most defensible and describe the others as sensitivity checks.
Wagner	In short, it is a clear step forward from the prior Interagency Working Group (2015) effort. If Rennert et al. (2022) is any guide here, it may also be the single most important update affecting the final number with the sole exception of assumed discount rates.
Wagner	At the same time, it may also be the module in need of most work. In particular, a closer look at the decomposition of the three damage modules (see e.g. Table 3.1.4) makes it unclear whether it is more appropriate to average across the three functions or perhaps even, in part, add them. DSCIM focuses on five sectors or impact categories, GIVE on four, leaving out labor productivity. The sole overlap in sources across the two is Diaz (2016) for sea-level rise damages. It would take quite a bit more work of diving into the specific sources to understand whether it is truly appropriate to average across them, or whether even adding (some of) the now separate damage modules might be more appropriate.
Wagner	Similarly, the damage function based on the Howard and Sterner (2017) meta-analysis is just that: a by now well-established analysis of several prior published results. It, too, is a clear step forward from the prior Interagency Working Group (2015) effort, tet some of these prior studies, by now, are rather outdated themselves and would deserve a second look. For example, mortality seems to barely figure into the calculation, once again raising the question of whether averaging across damage modules is the appropriate step, rather than adding some damage function components to those from DSCIM and GIVE.

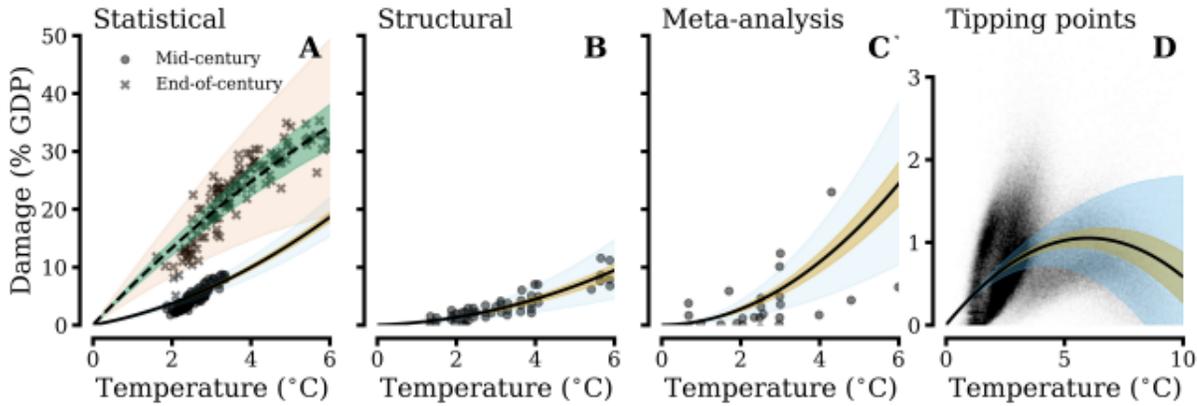
Charge Question 4.b. <i>Does the draft report’s use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes do you recommend? Do you think that there is a better approach for this update?</i>	
REVIEWER	REVIEWER COMMENT
Cropper	I have no further changes to suggest.
Fisher-Vanden	There are a number of integrated modeling studies that examine fine-scale impacts as part of the integrated assessment and multisector dynamics modeling communities, although this work is

Charge Question 4.b. <i>Does the draft report’s use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes do you recommend? Do you think that there is a better approach for this update?</i>	
REVIEWER	REVIEWER COMMENT
	focused on providing fine scale analysis rather than aggregate damage functions. Please see, for instance: https://climatemodeling.science.energy.gov/program-area/multisector-dynamics
Forest	At this time, the damage function module is in a state of flux as more damages are identified and not yet in the literature. So, it’s a moving target and will most likely always be an underestimate.
Kling	See above.
Oppenheimer	I believe that comparing results from these three research frameworks provides as credible an assessment as is now possible within the limitations of the modeling approaches deployed within each framework.
Oppenheimer	I worry much more about what was left out (see Table 3.2.1) as a source of error than I worry about the way the modeling of the included impacts was aggregated and the aggregations presented and compared. However, my concerns about the treatment of uncertainty and adaptation noted above remain.
Schlenker	I think the EPA has made a big step forward by switching to the modular approach and including three different damage approaches. The one exception is comment 2183, who talk about possible tipping points and encourage EPA to highlight them further. While I wouldn’t ask EPA to include them in their baseline numbers, it would be informative to include them in a sensitivity check to showcase how much they might change the results. One of the largest concerns for me about the current approach is that the approach might not correctly capture that we are setting irreversible self-enforcing feedback loops into motion and hence underestimate future damages.
Schlenker	As was discussed in our meeting, it would be great to stress that additional sectoral impacts will be added in the future. They might also result in benefits for some sector (e.g., recreation).
Wagner	One possible extension (or cross-check) here might be to look at the statistical damage functions presented by the IPCC (2022), in particular the Figure Cross-Working Group Box ECONOMIC.1, panels (a)-(c), p. 16-114.
Wagner	Another is to explicitly account for climatic tipping points, as in Dietz et al. (2021). Doing so alone would, according to our analysis, increase the SC-CO ₂ by between ~27-43%, with a potentially long right tail:

Charge Question 4.b. Does the draft report's use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes do you recommend? Do you think that there is a better approach for this update?

REVIEWER	REVIEWER COMMENT																																																																						
	<p>Economic impacts of tipping points in the climate system Tipping points increase SCC by between ~27-43%, with large, right-skewed distribution</p>  <table border="1" data-bbox="787 446 987 738"> <thead> <tr> <th colspan="2">Socio-economic scenario</th> </tr> </thead> <tbody> <tr> <td>RCP3-PD/2.6, SSP1</td> <td>33.8</td> </tr> <tr> <td>RCP4.5, SSP2</td> <td>24.5</td> </tr> <tr> <td>RCP6, SSP4</td> <td>15.4</td> </tr> <tr> <td>RCP8.5, SSP6</td> <td>19.4</td> </tr> <tr> <th colspan="2">Levels versus growth damages (φ)</th> </tr> <tr> <td>0.1</td> <td>21.9</td> </tr> <tr> <td>0.5</td> <td>24.5</td> </tr> <tr> <td>1</td> <td>26.0</td> </tr> <tr> <th colspan="2">Pure rate of time preference</th> </tr> <tr> <td>0.1</td> <td>22.3</td> </tr> <tr> <td>1</td> <td>24.5</td> </tr> <tr> <td>2</td> <td>26.3</td> </tr> <tr> <th colspan="2">Elasticity of marginal utility</th> </tr> <tr> <td>0.5</td> <td>22.0</td> </tr> <tr> <td>1.5</td> <td>24.5</td> </tr> <tr> <th colspan="2">Non-market damages</th> </tr> <tr> <td>Not included</td> <td>24.5</td> </tr> <tr> <td>Included</td> <td>26.9</td> </tr> <tr> <td colspan="2">+ other PCF and AMOC scenarios</td> </tr> </tbody> </table> <table border="1" data-bbox="1071 454 1186 609"> <thead> <tr> <th colspan="2">Average = 42.8%</th> </tr> </thead> <tbody> <tr> <td>0.5%</td> <td>= -48.1%</td> </tr> <tr> <td>2.5%</td> <td>= -0.3%</td> </tr> <tr> <td>25%</td> <td>= 16.1%</td> </tr> <tr> <td>Median</td> <td>= 27.3%</td> </tr> <tr> <td>75%</td> <td>= 42.1%</td> </tr> <tr> <td>97.5%</td> <td>= 186.0%</td> </tr> <tr> <td>99.5%</td> <td>= 347.8%</td> </tr> </tbody> </table> <table border="1" data-bbox="997 698 1165 787"> <thead> <tr> <th colspan="2">OMH scenario</th> </tr> </thead> <tbody> <tr> <td>Ceronsky et al. (2011)</td> <td>48.3</td> </tr> <tr> <td>7.8Gt/yr</td> <td></td> </tr> <tr> <th colspan="2">Elasticity of marginal utility</th> </tr> <tr> <td>2</td> <td>58.2</td> </tr> </tbody> </table> <table border="1" data-bbox="976 803 1165 852"> <thead> <tr> <th colspan="2">Levels versus growth damages (φ)</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>87.0</td> </tr> </tbody> </table> <p>Source: Dietz, Rising, Stoerk & Wagner (PNAS 2021), gwagner.com/tipping-economics</p>	Socio-economic scenario		RCP3-PD/2.6, SSP1	33.8	RCP4.5, SSP2	24.5	RCP6, SSP4	15.4	RCP8.5, SSP6	19.4	Levels versus growth damages (φ)		0.1	21.9	0.5	24.5	1	26.0	Pure rate of time preference		0.1	22.3	1	24.5	2	26.3	Elasticity of marginal utility		0.5	22.0	1.5	24.5	Non-market damages		Not included	24.5	Included	26.9	+ other PCF and AMOC scenarios		Average = 42.8%		0.5%	= -48.1%	2.5%	= -0.3%	25%	= 16.1%	Median	= 27.3%	75%	= 42.1%	97.5%	= 186.0%	99.5%	= 347.8%	OMH scenario		Ceronsky et al. (2011)	48.3	7.8Gt/yr		Elasticity of marginal utility		2	58.2	Levels versus growth damages (φ)		0	87.0
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Wagner	<p>That tail, in turn, leads to roughly a 1 in 10 chance of these eight modeled climatic tipping points more than doubling the SC-CO₂. We do so here in Figure 3 of Bauer, Proistosescu, and Wagner (2023):</p>																																																																						

Charge Question 4.b. *Does the draft report’s use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes do you recommend? Do you think that there is a better approach for this update?*

REVIEWER	REVIEWER COMMENT
	 <p>Figure 3: Damage functions. Shown are each of our damage functions by methodology (statistical, structural, and meta-analytic) as well as the marginal damages owing to tipping points. Note the statistical damage function shown assumes SSP2–4.5. In each panel, yellow shows ± 1 standard deviation in the damage function, while the blue shaded region shows ± 2 standard deviations. For the end of century estimates in panel A, the green region shown ± 1 standard deviation and the salmon shows ± 2 standard deviations.</p> <p>One striking observation: statistical “end-of-century” estimate might reverse the shape of the damage function from concave to convex. All this makes it important to highlight the large differences and resulting uncertainties across different assumed damage modules.</p>

Charge Question 4.c. *For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.*

REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	See comment in b.

Charge Question 4.c. For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.	
REVIEWER	REVIEWER COMMENT
Forest	N/A
Kling	See above.
Oppenheimer	I am not as expert on current valuation methods as others reviewing this report so I will refrain from commenting on this one.
Schlenker	The biggest sectoral impact is health (Table 3.1.4), which crucially depends on the value of a statistical life (VSL). There is an inherent tension between the current report and how EPA traditionally uses VSL. It is my understanding that EPA uses the same VSL for all ages (it once discussed using different values by age but then reverted back giving ethical considerations), even though there are revealed preference studies showing that it varies by age. Carleton et al. (2022) does use age-years lost, implying a different VSL per age group (older people have fewer life years left). Moreover, Carleton et al. (2022) uses an income-elasticity of one, which implies that if a person dies in a country that has one tenth of US income, it is valued at one tenth the US value. Scaling VSL by income has a theoretical and empirical underpinning: people who are faced with tradeoffs that can lower their mortality risk reveal a lower willingness to pay when their income is lower.
Schlenker	However, as comment 2464 points out, this is very different from the setting of greenhouse gas emissions where most of the emissions are caused by high-income developed countries, while most damages are felt in low-income countries (Figure 9 in Carleton et al). There is evidence that people care about the distributional aspects, e.g., Cai, Cameron, and Gerdes (2010) https://doi.org/10.1007/s10640-010-9348-7 I respectfully disagree with the comments made by Professor Kling. Again, there is a big difference whether people themselves make choices / tradeoffs between increased mortality risks and or whether it is imposed by others. There can be a big difference between willingness to pay and willingness to accept, see Hanemann (1991): https://www.jstor.org/stable/2006525 . In his proposition 2, he shows that if there is zero substitutivity, the former could be finite while the latter is infinite. So the VSL for action caused by others might be much higher. I am not aware of VSL studies in developing countries that look at harm (mortality risk) that is not endogenous to the country but caused by authors.

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REVIEWER	REVIEWER COMMENT
Schlenker	There is also an ethical perspective. The same studies, e.g., Viscusi and Masterman https://doi.org/10.1017/bca.2017.12 , that argue for an income elasticity of 1 for international setting, say it should be 0.5-0.7 for domestic setting. Yet, EPA does not differentiate VSLs by income within the US (New York has more than twice the average income than Mississippi, and we don't value deaths in Mississippi less than New York).
Schlenker	Let me illustrate the flip-side of this argument: the report outlined why using global impacts is appropriate, partly because we expect other countries to join in using similar regulation. It might be hard for the equivalent of EPA in India to argue to its citizens that a death in the US is 32 (current ratio of GDP per capita) as bad as a death in India.
Schlenker	What would be sensitivity of the SC-GHG to using different income-elasticities for the global VSL – I believe this should be discussed, at least in an appendix.
Wagner	See (b) above around the use of 'statistical' damage functions and especially also the tipping points component.

Charge Question 4.d. Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	(LONG-TERM): Indirect impacts and integrated impacts are very important and not considered in this report.
Forest	N/A
Kling	See above.
Oppenheimer	See my foregoing comments on precipitation and sea level rise adaptation.
Schlenker	EPA has based their analysis on three highly respected analyses (published in Nature and the Quarterly Journal of Economics) and incorporated the sectors used in those studies. I don't think it is realistic for EPA to add additional sectors that were not covered in the original studies. However, it might be good to note already now that future revisions will include additional sectors, however, I

Charge Question 4.d. Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.	
REVIEWER	REVIEWER COMMENT
	do believe that mortality will likely continue to be the most significant part (there is a reason studies focus on this sector first).
Wagner	Arguably the largest omission concerns climatic tipping points a al Dietz et al. (2021). ² ² Full disclosure: I am among the “et al”s.

Charge Question 4.e. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	(SHORT-TERM): As mentioned above, this report is excellent for providing an overview, but not appropriate for trying to understand and comment on what is going on under the hood. A much more detailed technical document, similar to the DSCIM user manual, for instance, is needed.
Forest	Not at this time.
Kling	See above.
Oppenheimer	No.
Schlenker	Since they are based on published studies, interested readers can revert to those studies. A few recommendations I have are: <ol style="list-style-type: none"> 1) Further outline the differences between studies for various sectors in Table 3.1.4. 2) Figure 2.3.2 plots the damage function. <ol style="list-style-type: none"> a) Please plot them all using the same y-scale so they are comparable. b) The one for the GIVE model seems to be consistently higher damages for various temperatures - I realize this is for damages in 2100 (one point in time) <ul style="list-style-type: none"> +1C: GIVE 1%, DSCIM: 0% +2C: GIVE 2.5%, DSCIM: 0%

Charge Question 4.e. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?

REVIEWER	REVIEWER COMMENT
	<p>+3C: GIVE 4%, DSCIM: 1% +4C: GIVE 5%, DSCIM: 2% +5C: GIVE 7.5%, DSCIM: 4% +6C: GIVE 10%, DSCIM: 6.5%</p> <p>Yet, the social cost of carbon is higher for DCSIM than GIVE. What is the intuition for this? Is it in the time profile (i.e., Figure 2.3.2 gives damages in 2100, where GIVE is higher, but DSCIM has higher damages by say mid-century?). But then, DSCIM gives lower SC-GHG for methane, which has a faster impact on warming and I would have expected the S-CH₄ methane to be even bigger under DSCIM model). Could you give some intuition how they compare over time.</p>
Wagner	<p>Instead of averaging across damage functions, a key improvement seems to be distinguishing between parametric uncertainty within any one damage function on the one hand, and structural uncertainty across different damage functions. In Bauer, Proistosescu, and Wagner (2023), for example, we explicitly account for both types of uncertainties. We make no judgment call over which damage function is more appropriate, nor do we average across them. We instead “assign a hyper-parameter in our simulated climate damages that randomly chooses a damage function,” allowing us “to remain agnostic with respect to which damage function we choose.” I would counsel a similar approach here.</p>
Wagner	<p>Meanwhile, at the very least, this module points once again to the appropriateness of calling the resulting SC-CO₂ a “partial” estimate, given that any of the individual damage functions used only account for some of the known climate impacts.</p>

Charge Question 4.f. Do you have longer-term recommendations for improvements to this module in future updates?

REVIEWER	REVIEWER COMMENT
Cropper	<p>When the climate module is able to produce estimates of precipitation and extreme weather events, damages associated with flooding will need to be included. As the report itself notes, there are many categories of damages, including tipping points (see Table 3.2.1).</p>
Fisher-Vanden	<p>See comments above.</p>

Charge Question 4.f. Do you have longer-term recommendations for improvements to this module in future updates?	
REVIEWER	REVIEWER COMMENT
Forest	The major advances must include more comprehensive impacts that will eventually need to be derived from higher complexity earth system models.
Kling	The last few paragraphs of section 3.2 suggest seemingly straightforward ways to include additional damage values into the SCC estimates, why not do them?
Oppenheimer	See above – the presentation is fine; the issue is the missing content.
Schlenker	EPA already outlined how they want to include other sectors, including non-market impacts. One important point to keep in mind when adding sectors and constructing confidence bands is that errors across sectoral impacts are likely highly correlated and not independent.
Schlenker	I believe there are especially two areas that warrant further study in the future that could significantly alter the overall results. First, one of the biggest unknowns is adaptation and whether it can significantly lower the predicted cost. The Carleton et al 2022 paper estimates adaptation based on revealed preferences of who has adapted so far in warmer climates, but are they representative? Full disclosure: it uses the same approach to adaptation that I have used before for crops - so the same criticism to applies to my studies. Specifically, areas that are currently warmer have lower crop yields (and lower GDP), so the benefits from innovation are currently lower than what they would be if currently moderate climates (with higher yields or GDP) become warmer. The incentives for innovation might hence be higher in the future as what is picked up in the current data. Moreover, the analysis omits that we might have new technologies available in the future that weren't available in the past. Taken together, we might underestimate adaptation possibilities and hence overestimate damages.
Schlenker	The second point relates to migration. In my opinion, one of the most disruptive effects of climate change might be the need to relocate – locally from flood-prone areas or even long-distance as regions become uninhabitable.
Wagner	Updating the damage function is among the most challenging tasks. The most important: arrive at a clear process to continuously update the damage function module with the latest scientific estimates (see section 1d above).

Charge Question 5.

Charge Question 5.a. Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?

REVIEWER	REVIEWER COMMENT
Cropper	<p>When discounting climate damages, it is important to allow for the correlation between damages and the rate of growth in the economy—i.e., to allow for systemic risk (see, e.g., Gollier, <i>AEA Papers and Proceedings</i> 2014). Using constant exponential discounting does not allow for this. The consequences of ignoring the correlation between economic growth and damages have been illustrated in the RFF Brookings Paper https://www.brookings.edu/wp-content/uploads/2021/09/15985-BPEA-BPEA-FA21_WEB_Rennert-et-al.pdf</p> <p>When there is considerable uncertainty in damages, failure to allow for this correlation can (incorrectly) increase the SCC by a factor of 10.</p>
Fisher-Vanden	<p>The Ramsey formulation adopted in this section is an improvement over past discounting approaches, in my opinion since it allows for dynamic discount rates and long-term intertemporal trade-offs which is key to the climate change issue.</p>
Fisher-Vanden	<p>What is interesting, though, is that the discount rates generated from this approach are not that far off from discount rates used in the IWG, although in this approach, discount rates fall slightly over time and uncertainty ranges include significantly higher and lower discount rates.</p>
Forest	<p>Not at this time.</p>
Kling	<p>This area is better addressed by other reviewers.</p>
Oppenheimer	<p>Better for others to handle this one.</p>
Schlenker	<p>The update module provides a theoretical underpinning for why the chosen interest rates are used that are in line with the recommendation of NASEM. While some comments (e.g., 2253) have argued that an interest of zero is appropriate, I do not find this convincing.</p>
Schlenker	<p>The Ramsey formula is a composite of a pure time preference (which one might argue should be set to zero) and a second term that incorporates that future generation are better off (wealthier) than the current generation. Taking money from the (poorer) present and consuming it in the (wealthier) future, when the value of having an extra dollar is lower, leads to a welfare decline. Within this framework, the only reason that we discount with the second term is because the future is better off.</p>

Charge Question 5.a. Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?	
REVIEWER	REVIEWER COMMENT
	If climate change were so catastrophic that the future is worse off than the present, the interest rate would actually be negative. This might be worth highlighting.
Wagner	Discounting has the single largest impact on the SC-CO ₂ . The discounting module applied in the EPA report appropriately represents the biggest advance from the prior SC-CO ₂ efforts. It is based on Newell, Pizer, and Prest (2022), which drives a relatively simple yet well-founded “discounting rule” for the SC-CO ₂ .
Wagner	The arguments for using a 2% ‘central’ estimate and values of 1.5% and 2.5% around it, in turn, are well-founded in economic theory and in recent advances in empirical understanding (e.g. Drupp et al. 2018; Council of Economic Advisors 2017; Greenstone and Stock 2021; Wagner et al. 2021). In fact, as I mention above, the proposed update to Circular A-4 argues convincingly for an even lower discount rate of 1.7% to be used in the short term (U.S. Office of Management and Budget (OMB) 2023). This might well argue for an even lower ‘central’ estimate than the current 2%.

Charge Question 5.b. Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.	
REVIEWER	REVIEWER COMMENT
Cropper	I would not consider alternative approaches.
Fisher-Vanden	I defer to others on the review panel who are better equipped to comment on this.
Forest	Not at this time.
Kling	This area is better addressed by other reviewers.
Oppenheimer	Same as (a).
Schlenker	I believe the Ramsey formula is appropriate.
Wagner	No. Ramsey discounting is the appropriate methodology here. As I mentioned in (1c) above, and as alluded to in the document, there are alternative approaches to Ramsey discounting, in particular use of Epstein-Zin utility functions (Epstein and Zin 1989; 1991; Weil 1990).

Charge Question 5.b. <i>Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.</i>	
REVIEWER	REVIEWER COMMENT
Wagner	This literature is worthy of further exploration, though despite important contributions to date (Lemoine and Rudik 2017), and my own participation in this literature (Daniel, Litterman, and Wagner 2018; 2019; Bauer, Proistosescu, and Wagner 2023), I do not believe that work on Epstein-Zin-style utility functions are ripe to supplant standard Ramsey discounting approaches in calculating the formal U.S. SC-CO ₂ .

Charge Question 5.c. <i>Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.</i>	
REVIEWER	REVIEWER COMMENT
Cropper	The advantage of the current calibration of Ramsey discounting is that it links the initial discount rate to market rates of interest. The US government has always adhered to a positive, rather than a normative, approach to discounting. This helps to preserve this approach, while allowing for the correlation described in Comment a.
Fisher-Vanden	I defer to others on the review panel who are better equipped to comment on this.
Forest	Not at this time.
Kling	This area is better addressed by other reviewers.
Oppenheimer	Same as (a).
Schlenker	No comment.
Wagner	n/a

Charge Question 5.d. <i>Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?</i>	
REVIEWER	REVIEWER COMMENT
Cropper	None.

Charge Question 5.d. <i>Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?</i>	
REVIEWER	REVIEWER COMMENT
Fisher-Vanden	Unlike some of the other sections of the report, I felt like this section did a better job providing the details needed to understand what was being done, although I did end up reading some of the cited articles to get a fuller understanding of the approach and calibration.
Forest	Not at this time.
Kling	This area is better addressed by other reviewers.
Oppenheimer	Same as (a).
Schlenker	See part a. Maybe describe why the interest rate is positive in more detail and under what conditions it would be negative.
Wagner	Yes, and no. This module might be the most challenging to get right, and the EPA report does a great job of explaining the intricacies in plain language. The discounting module is clearly written, and deserves wide circulation on its own as a standard entry into this literature.

Charge Question 5.e. <i>Do you have longer term recommendations for improvements to this module in future updates?</i>	
REVEIWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	I defer to others on the review panel who are better equipped to comment on this.
Forest	Not at this time.
Kling	This area is better addressed by other reviewers.
Oppenheimer	Same as (a).
Schlenker	No comment.
Wagner	The key bit for longer-term updates, here as elsewhere, is around setting up the appropriate process to help identify conditions under which the discount rates used here might be updated. One such example is our improved understanding of the appropriate “climate beta” (Dietz, Gollier, and Kessler 2018; Lemoine 2021), which may well merit updates to the discounting module in the future.

Charge Question 6.

Charge Question 6.a.i. *Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?*

REVIEWER	REVIEWER COMMENT
Cropper	The current approach more adequately captures risk preferences than the previous ad hoc adjustment of constant exponential discount rates and the focus on the 95 th percentile of the SCC. The discussion of risk aversion in the current draft is excellent.
Fisher-Vanden	I believe the methodological approach to account for risk aversion is consistent with the discounting approach and an improvement over past studies.
Forest	No comment.
Kling	Yes, this is a much-improved approach.
Oppenheimer	Better for others to handle this.
Schlenker	Comment 2183 had some useful suggestions on going from a positive to normative justification for the chosen interest rate – this would be worth considering when providing justification, as well discussion on the climate beta. The comment is a better summary than what I can provide.
Wagner	The treatment of risk aversion poses the largest challenge to the standard Ramsey discounting framework and all but calls for using Epstein-Zin-style preferences. I do not, however, believe that literature is ripe for incorporating here (see 5b above).

Charge Question 6.a.ii. *Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.*

REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	I defer to others on the review panel who are better equipped to comment on this.
Forest	No comment.

Charge Question 6.a.ii. <i>Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.</i>	
REVIEWER	REVIEWER COMMENT
Kling	No.
Oppenheimer	Better for others to handle this.
Schlenker	No comment.
Wagner	One important addition is adding at least one scenario/model run that explicitly factors in “equity weights” (e.g. Anthoff and Emmerling 2018). This is especially appropriate given the theoretical problems with using the EPA report’s Purchasing Power Parity (PPP) adjustment of the estimate of a Value of a Statistical Life (VSL) and claims around the application of the Kaldor-Hicks criterion (see 6bi below).

Charge Question 6.a.iii. <i>Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?</i>	
REVIEWER	REVIEWER COMMENT
Cropper	As noted above, the discussion of the current parameterization of η is very clear and I agree with the current choices.
Fisher-Vanden	This section, in contrast with other sections, was better at being transparent and forthcoming with the biases to the SC-GHG estimates resulting from their choice of parameter values (e.g., bottom of pages 64 and 65). This type of transparency is needed throughout the report.
Forest	Not at this time.
Kling	My primary suggestion for this section is to provide more information and tables comparing the results. Table 3.1.1 – 3.1.3 report the SC-GHGs by sector by damage module, but not by “sector”. To better compare and understand differences and similarity in the 3 damage modules, it would be very useful to see these disaggregated by sector and by region of the world. Table 3.1.4 does provide a comparison across sectors by only for a single year, not its time path over time and not by geography region.
Kling	The welfare gain predicted for the DSCIM energy estimates reported in Table 3.1.4 needs explanation. My suspicion is that this reflects the lower bound nature of an expenditure change relative to the underlying welfare measure being sought to estimate (see Bartik bounds and related

Charge Question 6.a.iii. Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?	
REVIEWER	REVIEWER COMMENT
	work).
Kling	I encourage EPA to provide physical effects of whatever damage categories they can that are not monetized even if monetization is a ways off. This is consistent with best practices as articulated in EPA's Guidance for Economic Analysis and was recommended by the NASEM report. I also feel that it would add transparency.
Oppenheimer	Better for others to handle this.
Schlenker	No comment.
Wagner	[n/a]

Charge Question 6.a.iv. Do you have longer run recommendations for improved ways to account for risk aversion in future updates?	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	I defer to others on the review panel who are better equipped to comment on this.
Forest	The psychological and behavioral sciences will need to be considered to address long-term risks. The mainstream discussions of observed climate changes based on the historical climate records does not fully account for the radiative forcing due to the emissions in the last few decades.
Forest	The current younger generations will be experiencing the climate change from the accumulated forcing from the past 30-40 years. The assessments of risk aversion should be stratified by age and use tools such as the assessment "Global Warming's Six Americas" from the Yale Program on Climate Change Communication. Other global projects to assess risk aversion through surveys need to be considered on this topic.
Kling	No.
Oppenheimer	Better for others to handle this.
Schlenker	No comment.

Charge Question 6.a.iv. Do you have longer run recommendations for improved ways to account for risk aversion in future updates?

REVIEWER	REVIEWER COMMENT
Wagner	Include Epstein-Zin preferences, potentially as a scenario/model run, much like factoring in equity weights (see 5b above.) Doing so will allow for an explicit exploration of higher—and perhaps more appropriate—risk-aversion parameters than are currently used.

Charge Question 6.b.i. Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?

REVIEWER	REVIEWER COMMENT
Cropper	The DSCIM authors have made the spatial distribution of climate damages (e.g., for mortality, energy consumption) clear in their published work. I think it is fine to refer to the reader of the TSD to these papers.
Fisher-Vanden	The DSCIM damage estimates are done at a very fine spatial scale and would allow for distribution impacts to be captured if integrated into the right socioeconomic model. As I recommend above in section 2a., this provides further support for taking a hybrid approach with the socioeconomic projections since the structural economy-wide models are becoming finer scale (even down to the country level) to allow for these types of distributional effects to be captured.
Fisher-Vanden	(LONG-TERM): it will be important in future SC-GHG estimates to capture feedbacks, interactions, and intra- and international trade to truly capture the distributional impacts of climate change. There are plenty of studies that have shown the importance of this.
Forest	Improvements will need to use existing weather and climate models and identify how resolution is currently limiting the evaluation of extreme events. Emulators of weather extremes are new and valuable tools that are more available in the insurance industry (aka catastrophe models). Precipitation and wind extremes are not resolved at scales that are not in any current regional or global models. The development of these tools in the environmental modelling research area are only now becoming available.
Forest	An additional component is how to extract information for damage functions that are not explicitly modeled. The non-linear models will need multiple inputs (e.g., wind, humidity, air quality, temperature, etc.) that are currently being developed for individual cities. A comprehensive assessment probability functions are not capable to capture the concurrent extremes that would require more than one from the long list of inputs.

Charge Question 6.b.i. <i>Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?</i>	
REVIEWER	REVIEWER COMMENT
Kling	Presenting physical impacts by region as well as monetized impacts might help provide a more thorough understanding of the distributional effects.
Oppenheimer	Given the high spatial resolution of the impact models, it seems a pity that ways could not be found to estimate distributional impacts beyond the mostly descriptive statements in the report. The next generation of SCC assessments should make it a priority to determine which constraints are limiting and develop estimation procedures to overcome these limitations.
Oppenheimer	Once again, taking an approach that emphasizes plausible upper and lower bounds on distributional consequences could provide useful information for policy makers even before end-to-end high-resolution modeling is available, even if not totally consistent with the aspiration for the sort of quantitative distributions derived in this report.
Schlenker	Several of the critical comments highlighted the cost imposed on local natural gas producers. It is standard practice for studies using the Kaldor-Hicks criterion to weight losses against gains, without actually making transfer payments. However, as Arrow et al (1996) (https://doi.org/10.1126/science.272.5259.221) point out, “Although benefit-cost analysis should focus primarily on the overall relation between benefits and costs, a good analysis will also identify important distributional consequences.” While the overall benefits clearly swamp the cost, does EPA have ideas or recommendations on how the most negatively impacted communities can be helped.
Wagner	One key assumption behind the distributional impacts of climate change is the EPA report’s PPP-adjustment of the estimate of a Value of a Statistical Life (VSL). While this application seems appropriate at first glance, it is theoretically and practically inconsistent with a strict interpretation of the Kaldor-Hicks criterion (Bressler and Heal 2022)..
Wagner	Furthermore, doing so departs from OMB’s previous guidance “for treating equally persons of different income levels at a given time, for the purposes of valuation” (National Academy of Sciences 2017, 183). A full reconciliation of theory and practice would be difficult. I would, thus, counsel to treat the PPP-adjusted estimates as one possible scenario and also present a scenario that explicitly includes equity weights, while removing the erroneous “Kaldor-Hicks” justification for using PPP-adjusted VSL estimates. ³

Charge Question 6.b.i. <i>Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?</i>	
REVIEWER	REVIEWER COMMENT
	³ It is important to note here that the newly released draft Circular A-4 explicitly permits equity weights in regulatory analysis (U.S. Office of Management and Budget (OMB) 2023)

Charge Question 6.b.ii. <i>Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?</i>	
REVIEWER	REVIEWER COMMENT
Cropper	In section 1.2, the report does note the NRC arguments for looking at global damages, even if one is interested only in impacts on the US.
Fisher-Vanden	(SHORT-TERM): Again, reading other documentation was essential to being able to understand this. The report does not provide enough detail.
Forest	While it is not my expertise, I support improvements in the estimation approaches that would address how to provide global SC-GHG estimates that could influence economic damages through global mechanisms like supply chains or pandemics.
Kling	The explanation provided for using global damages vis-à-vis the effect of not doing so for US citizens is well stated. From the perspective of a worldwide social planner, there is of course another important reason for urging a global number. If each country were to design policy to equate marginal damages with marginal abatement costs using only the damages their pollution inflicts on their own citizens, the world would not achieve the socially optimal level of emissions as many damages would be omitted.
Oppenheimer	Damages to the US are discussed in several specific contexts, for instance, sectors not included in this report’s SCC results because a basis for producing global numbers is lacking. However, no overall comparison of US-only and global values is highlighted – if it’s there the reader must search hard to find it. This may have been seen as appropriate following the guidance to derive values of SCC encompassing global damages.
Oppenheimer	Nevertheless, US-only numbers would be interesting material for the report to highlight and discuss.

Charge Question 6.b.ii. Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?	
REVIEWER	REVIEWER COMMENT
Schlenker	The report is clear in why it uses global numbers. I support the approach taken. In a global public goods setting, the solution to the problem where every country only focuses on their domestic benefits. Cost will be suboptimal. Comment 2281 provides further arguments for why this is appropriate – I am not a legal scholar so defer to those arguments.
Wagner	The EPA report should explicitly discuss the importance of equity weights in calculating the SC-CO ₂ relative to the current practice of PPP-adjusted VSL figures.

Charge Question 6.b.iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?	
REVIEWER	REVIEWER COMMENT
Cropper	None.
Fisher-Vanden	See above.
Forest	Not at this time.
Kling	No.
Oppenheimer	No.
Schlenker	I feel it is clearly written and makes adjustments in response to the recommendation by NASEM. The only recommendation I have is the discussion around Table 3.1.4. It would be informative to get further insights for why the analyses are so different for some sectors, especially agriculture, the sector where DSCIM and GIVE diverge the most.
Wagner	My biggest direct criticism of the writing and presentation of the EPA report concerns its treatment of risks and uncertainties.
Wagner	While the report itself goes into detail on the generally impressive effort to model climatic and climate-economic risks and uncertainties, Table ES.1 in the Executive Summary, arguably the most important table of the entire document, appears to take a step backwards in presenting these risks and uncertainties. The prior Obama-era effort presented three columns for the SC-CO ₂ : three different discount rates, plus the 95 th percentile of the distribution for the ‘central’ discount rate (U.S.

Charge Question 6.b.iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?	
REVIEWER	REVIEWER COMMENT
	Government Interagency Working Group on Social Cost of Carbon 2015). While most readers of the report still zeroed in on the ‘central’ ~\$50 value, the table clearly showed the importance of considering the tail of the SC-CO ₂ distribution.
Wagner	The current presentation in the Executive Summary and in Table ES.1 appropriately rounds the numbers to avoid false precision, but it does not present the potentially long right tail of the SC-CO ₂ . Figure 3.1.1 does so on page 69 of the draft. Finding a way to represent this range in the Executive Summary is crucial, and it might well be best accomplished by putting the same figure in the ES.
Wagner	<p>Doing so might involve modifying Figure 3.1.1 to represent the full distribution of possible values, akin to Figure 2 in Rennert et al (2022):</p> <p>~\$185 Social Cost of CO₂ Based on 2% constant discount rate, with potentially long right tail</p> <p style="text-align: center;">SC-CO₂ (US\$ per tonne of CO₂)</p> <p>Source: Rennert et al "Comprehensive Evidence Implies a Higher Social Cost of CO₂" (Nature, September 2022).</p>

Charge Question 6.c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?	
REVIEWER	REVIEWER COMMENT
Cropper	No further comments. This is an excellent report.
Fisher-Vanden	(LONG-TERM): The point was raised in the second meeting (and in the report) that it is important to capture global impacts since there are spillovers (and not to take a partial “only damages to the US” approach when generating the SC-GHG estimates). I agree but wonder how this would be captured without the explicit modeling of trade, as discussed above in my comments.
Forest	My co-evaluators emphasized that the current SC-GHGs is only a partial estimate. By recognizing this, we must put more effort to understand the global response to climate change damages that will be influencing all regions of the world (populated or not). We need to develop additional metrics to account for the non-US impacts and damages. From the climate science side, this will require improving the impacts and damage estimates for all parts of the world and would require specific IPCC research agendas to develop and account for the full global estimates of Social Costs of Greenhouse Gases among all countries.
Kling	No.
Oppenheimer	See subparts.
Schlenker	Let me restate some of the longer-term issues that are outstanding, some of which I discussed before: 1) Include additional sectors (including migration), as well as correlation between sectoral damage estimates
Schlenker	2) Several studies suggest that extreme temperatures and precipitation events cause especially large damages, so incorporate climate extremes and how they evolve.
Schlenker	3) Include feedbacks between damage module and socio-economic module, model price effects.

REVIEWER		REVIEWER COMMENT
<p>Charge Question 6.c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?</p>		
Schlenker		4) Innovation and adaptation potential – do we correctly capture what will be available going forward. It is an active research area, and I would encourage EPA to incorporate new findings as they become available.
Wagner		My largest long-term comment concerns the treatments of risk aversion and equity weights, reflected in (6a) and (6b) above, respectively. The EPA report appropriately strives to base the SC-CO ₂ in the long-standing application of the Kaldor-Hicks potential compensation criterion. Equity weights within and across countries might lead to a more direct and, thus, appropriate consideration of differing impacts of climate change.
Wagner		Appropriately applying equity weights, in turn, could be based on one of two methods: calibrating based on observed behavior of how averse to inequality society is, or based on ethical views of how adverse to inequality society should be (Wagner et al. 2021). Picking the ‘correct’ equity weights, thus, mirrors the process of picking the correct discount rates, and doing so will be no less important to the resulting SC-CO ₂ . Something similar goes for risk aversion.

III. Specific Observations			
Reviewer	Page	Paragraph	Comment or Question
Cropper			No comments.
Fisher-Vanden			No comments.
Forest			No comments.
Kling	5		the “fourth” value should be “third”
Kling	18		clarify that the report uses “income” as equivalent to “GDP”

III. Specific Observations			
Reviewer	Page	Paragraph	Comment or Question
Oppenheimer			No comments.
Schlenker	51	Figure 2.3.2	I think comparison across the three models would be easier if each of the three plots use the same 0-20% scale for the y-axis.
Wagner			<p>Aldy, Joseph E., Matthew J. Kotchen, Robert N. Stavins, and James H. Stock. 2021. “Keep Climate Policy Focused on the Social Cost of Carbon.” <i>Science</i> 373 (6557): 850–52.</p> <p>Anthoff, David, and Johannes Emmerling. 2018. “Inequality and the Social Cost of Carbon.” <i>Journal of the Association of Environmental and Resource Economists</i> 6 (2): 243–73. https://doi.org/10.1086/701900.</p> <p>Arkolakis, Costas, and Conor Walsh. 2023. “Clean Growth.” Columbia Business School working paper.</p> <p>Barrage, Lint, and William D. Nordhaus. 2023. “Policies, Projections, and the Social Cost of Carbon: Results from the DICE-2023 Model.” Working Paper. Working Paper Series. National Bureau of Economic Research. https://doi.org/10.3386/w31112.</p> <p>Bauer, Adam Michael, Cristian Proistosescu, and Gernot Wagner. 2023. “Carbon Dioxide as a Risky Asset.” Working Paper 10278. CESifo. https://gwagner.com/cap6/.</p> <p>Bressler, R. Daniel, and Geoffrey Heal. 2022. “Valuing Excess Deaths Caused by Climate Change.” Working Paper 30648. National Bureau of Economic Research.</p> <p>Carleton, Tamma, and Michael Greenstone. 2021. “Updating the United States Government’s Social Cost of Carbon.” Working Paper No. 2021-04. University of Chicago, Becker Friedman Institute for Economics.</p>

III. Specific Observations			
Reviewer	Page	Paragraph	Comment or Question
			<p>Christensen, P., K. Gillingham, and W. Nordhaus. 2018. “Uncertainty in Forecasts of Long-Run Economic Growth.” <i>Proceedings of the National Academy of Sciences</i> 115 (21): 5409–14. https://doi.org/10.1073/pnas.1713628115.</p> <p>Council of Economic Advisors. 2017. “Discounting for Public Policy: Theory and Recent Evidence on the Merits of Updating the Discount Rate.” Washington, DC. https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf.</p> <p>Daniel, Kent D., Robert B. Litterman, and Gernot Wagner. 2018. “Applying Asset Pricing Theory to Calibrate the Price of Climate Risk.” Working Paper 22795. National Bureau of Economic Research. https://doi.org/10.3386/w22795.</p> <p>———. 2019. “Declining CO2 Price Paths.” <i>Proceedings of the National Academy of Sciences</i>, October, 201817444. https://doi.org/10.1073/pnas.1817444116.</p> <p>Diaz, Delavane B. 2016. “Estimating Global Damages from Sea Level Rise with the Coastal Impact and Adaptation Model (CIAM).” <i>Climatic Change</i> 137 (1): 143–56. https://doi.org/10.1007/s10584-016-1675-4.</p> <p>Dietz, Simon, Christian Gollier, and Louise Kessler. 2018. “The Climate Beta.” <i>Journal of Environmental Economics and Management</i> 87: 258–74.</p> <p>Dietz, Simon, James Rising, Thomas Stoerk, and Gernot Wagner. 2021. “Economic Impacts of Tipping Points in the Climate System.” <i>PNAS</i> 118 (34): e2103081118. https://doi.org/10.1073/pnas.2103081118.</p> <p>Drupp, Moritz A., Mark C. Freeman, Ben Groom, and Frikk Nesje. 2018. “Discounting Disentangled.” <i>American Economic Journal: Economic Policy</i> 10 (4): 109–34. https://doi.org/10.1257/pol.20160240.</p>

III. Specific Observations			
Reviewer	Page	Paragraph	Comment or Question
			<p>Epstein, Larry G., and Stanley E. Zin. 1989. “Substitution, Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: A Theoretical Framework.” <i>Econometrica</i> 57 (4): 937–69. https://doi.org/10.2307/1913778.</p> <p>———. 1991. “Substitution, Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: An Empirical Analysis.” <i>Journal of Political Economy</i> 99 (2): 263–86.</p> <p>Gillingham, Kenneth, and James H. Stock. 2018. “The Cost of Reducing Greenhouse Gas Emissions.” <i>Journal of Economic Perspectives</i> 32 (4): 53–72. https://doi.org/10.1257/jep.32.4.53.</p> <p>Greenstone, Michael, and James H. Stock. 2021. “The Right Discount Rate for Regulatory Costs and Benefits.” <i>Wall Street Journal</i>, March 4, 2021, sec. Life. https://www.wsj.com/articles/the-right-discount-rate-for-regulatory-costs-and-benefits-11614870636.</p> <p>Howard, Peter H., and Thomas Sterner. 2017. “Few and Not So Far Between: A Meta-Analysis of Climate Damage Estimates.” <i>Environmental and Resource Economics</i> 68 (1): 197–225. https://doi.org/10.1007/s10640-017-0166-z.</p> <p>IPCC. 2022. “IPCC Sixth Assessment Report, Summary for Policy Makers: Climate Change 2022 Mitigation of Climate Change.” Assessment Report. Intergovernmental Panel on Climate Change. https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf.</p> <p>Lemoine, Derek. 2021. “The Climate Risk Premium: How Uncertainty Affects the Social Cost of Carbon.” <i>Journal of the Association of Environmental and Resource Economists</i> 8 (1): 27–57.</p>

III. Specific Observations			
Reviewer	Page	Paragraph	Comment or Question
			<p>Lemoine, Derek, and Ivan Rudik. 2017. “Managing Climate Change Under Uncertainty: Recursive Integrated Assessment at an Inflection Point.” <i>Annual Review of Resource Economics</i> 9 (1): 117–42. https://doi.org/10.1146/annurev-resource-100516-053516.</p> <p>Moore, Frances C., and Delavane B. Diaz. 2015. “Temperature Impacts on Economic Growth Warrant Stringent Mitigation Policy.” <i>Nature Climate Change</i> 5 (2): 127–31. https://doi.org/10.1038/nclimate2481.</p> <p>Moore, Frances C., James Rising, Simon Dietz, Moritz Drupp, Ivan Rudik, and Gernot Wagner. 2023. “Structural Modelling Changes Drive the Social Cost of Carbon.” Presented at the CESifo Area Conference on Energy and Climate Economics, Munich, March 10.</p> <p>National Academy of Sciences. 2017. <i>Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide</i>. https://www.nap.edu/catalog/24651/valuing-climate-damages-updating-estimation-of-the-social-cost-of.</p> <p>Newell, Richard G., William A. Pizer, and Brian C. Prest. 2022. “A Discounting Rule for the Social Cost of Carbon.” <i>Journal of the Association of Environmental and Resource Economists</i> 9 (5): 1017–46.</p> <p>Proistosescu, Cristian, and Gernot Wagner. 2020. “Uncertainties in Climate and Weather Extremes Increase the Cost of Carbon.” <i>One Earth</i> 2 (6): 515–17. https://doi.org/10.1016/j.oneear.2020.06.002.</p> <p>Rennert, Kevin, Frank Errickson, Brian C. Prest, Lisa Rennels, Richard G. Newell, William Pizer, Cora Kingdon, et al. 2022. “Comprehensive Evidence Implies a Higher Social Cost of CO₂.” <i>Nature</i>, September. https://doi.org/10.1038/s41586-022-05224-9.</p>

III. Specific Observations			
Reviewer	Page	Paragraph	Comment or Question
			<p>Sherwood, S. C., M. J. Webb, J. D. Annan, K. C. Armour, P. M. Forster, J. C. Hargreaves, G. Hegerl, et al. 2020. “An Assessment of Earth’s Climate Sensitivity Using Multiple Lines of Evidence.” <i>Reviews of Geophysics</i> 58 (4): e2019RG000678. https://doi.org/10.1029/2019RG000678.</p> <p>Stern, Nicholas, and Joseph E. Stiglitz. 2021. “The Social Cost of Carbon, Risk, Distribution, Market Failures: An Alternative Approach.” Working Paper 28472. National Bureau of Economic Research.</p> <p>U.S. Government Interagency Working Group on Social Cost of Carbon. 2015. “Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.”</p> <p>https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf.</p> <p>U.S. Office of Management and Budget (OMB). 2023. “Circular A-4.” https://www.whitehouse.gov/wp-content/uploads/2023/04/DraftCircularA-4.pdf.</p> <p>Wagner, Gernot. 2021. “Recalculate the Social Cost of Carbon.” <i>Nature Climate Change</i> 11 (4):293–94. https://doi.org/10.1038/s41558-021-01018-5.</p> <p>Wagner, Gernot, David Anthoff, Maureen Cropper, Simon Dietz, Kenneth T. Gillingham, Ben Groom, J. Paul Kelleher, Frances C. Moore, and James H. Stock. 2021. “Eight Priorities for Calculating the Social Cost of Carbon.” <i>Nature</i> 590 (7847): 548–50. https://doi.org/10.1038/d41586-021-00441-0.</p> <p>Wagner, Gernot, and Julio Friedmann. 2023. “3 Ways America Can Spend Biden’s Clean-Energy Windfall Faster.” <i>Washington Post</i>, March 13, 2023, sec. Opinions. https://wapo.st/3Td2A63.</p>

III. Specific Observations			
Reviewer	Page	Paragraph	Comment or Question
			Weil, Philippe. 1990. "Nonexpected Utility in Macroeconomics." <i>The Quarterly Journal of Economics</i> 105 (1): 29–42. https://doi.org/10.2307/2937817 .

IV. INDIVIDUAL PEER REVIEWER COMMENTS

Maureen Cropper, PhD

Peer Review Comments on the TSD: Social Cost of Greenhouse Gas

Maureen Cropper, PhD

I. GENERAL IMPRESSIONS

EPA's Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances represents a huge advance in estimating the US Social Cost of Carbon (SCC). The estimates reported have successfully incorporated all of the short-term recommendations of the National Research Council (NRC) Committee on Valuing Climate Damages, and some of the longer-term recommendations. The report represents the state-of-the-art in executing the four steps of SCC calculation: (1) calculating probability distributions over future paths of population, GDP and emissions; (2) translating future emissions into future climate impacts; (3) estimating net damages associated with changes in climate; (4) discounting future damages to the present. The description in the report of these steps and how they were executed is excellent. While the current report admittedly does not cover all aspects of climate change (e.g., precipitation impacts and extreme weather events) and all categories of damages (e.g., the impacts of flooding) I believe that the information presented is accurate and that the conclusions reached are sound.

II. RESPONSE TO CHARGE QUESTIONS

1. *Use of a modular approach to the methodological updates*

Consistent with the National Academies' near-term recommendations, EPA separately updates the methodology in each step of the SC-GHG estimation—socioeconomic and emissions projections, climate science, economic damages, and discounting—increasing transparency and ease of updating each component to reflect the latest expertise from the scientific disciplines relevant to that component. Using this modular approach, EPA updated each step in SC-GHG estimation to improve consistency with the current state of scientific knowledge, enhance transparency, and allow for a more explicit representation of uncertainty.

- a. *Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

The use of a modular approach is a significant improvement over the bundling of DICE2013, PAGE and FUND. While each of these integrated assessment models (IAMs) has played an important role in enriching our understanding of the nature of climate change and policies to control it, the versions used to construct the interim SCC did not reflect the state of the art in climate science or in the modeling of climate damages. The advantage of the modular approach is that each of the four steps of SCC estimation can be executed by experts in the relevant area.

- b. *Was the modular approach described clearly in the draft report? Do you have any*

recommendations for improving the presentation in the draft report?

I think it is well described.

- c. *Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.*

None.

- d. *Do you have longer term recommendations regarding approaches the EPA should consider for future updates?*

In the longer term, as the NRC recommended, there need to be feedbacks among modules. If along a particular socioeconomic path there is a high probability of a negative climate outcome, and significant damages, this will reflect GDP along the path.

2. Socioeconomic and emissions module

The socioeconomic and emissions module used in the draft report relies on a new set of socioeconomic and emissions projections developed under the Resources for the Future Social Cost of Carbon Initiative (collectively referred to as the RFF-SPs) (Rennert et al. 2022a). The RFF-SPs are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO₂, CH₄, and N₂O) to 2300 that were generated using statistical and structured expert judgement methods and accounting for future policies and interdependencies. The country-level population projections extend the fully probabilistic statistical approach used by the United Nations for official population forecasts, while incorporating improvements recommended by a panel of expert demographers (Raftery and Ševčíková 2021). The country-level empirical economic growth projections (Müller, Stock, Watson 2020) were extended in time using expert elicitation (Rennert et al. 2022a). The emissions projections are conditioned on future economic growth and a reflection of an “Evolving Policies” case (Rennert et al. 2022a).

- a. *Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?*

The RFF-SPs are a huge improvement over the five equally likely scenarios from the Energy Modeling Forum that constituted the SPs in previous estimates of the SCC. The RFF-SPs are based on econometric analysis (for GDP growth) combined with expert elicitation, using experts in each field. In most cases, the probability distributions for each SP span the values produced by the IPCC Shared Socioeconomic Pathways. This is a useful point of comparison, although the SSPs are not probabilistic.

- b. *Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages*

of these approaches.

None

- c. Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?*

None

- d. Do you have longer-term recommendations for improvements to this module in future updates?*

As noted above, there should, ideally be feedbacks from the damages module to the socioeconomic pathways. This is something for future research.

3. Climate module

EPA's goal for this update of the climate module was to adopt a widely used, transparent climate model that could reflect the latest scientific understanding of the relationships between CO₂ emissions, atmospheric CO₂ concentrations, and global mean surface temperature change (and any other climatic variables required as inputs to the damage module) over time while accounting for non-CO₂ forcing and allowing for the evaluation of uncertainty. The climate module used in the draft report relies on the open source and widely used Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature change. The estimates presented in the report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b), in which the uncertain parameters have been calibrated to be consistent with the most recent assessment of the IPCC, such as the IPCC AR6 assessed likely range of 2.5 to 4°C for the equilibrium climate sensitivity.

- a. Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?*

The FAiR model improves significantly upon the climate portions of DICE2013, FUND and PAGE. These IAMs do not reflect the latest climate science (e.g., Joos et al. 2013) which suggests that the maximum impact of a pulse of CO₂ on mean global temperature will be felt within 20 years. (See also Figure A.5.7 in the Appendix.) The FAiR model was developed by members of the NRC committee in response to their criticisms of the climate portions of DICE, FUND and PAGE.

- b. Are there additional or alternative existing climate models that can be used to reflect*

the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.

None.

- c. *Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.*

None.

- d. *Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?*

None.

- e. *Do you have longer-term recommendations for improvements to this module in future updates?*

None.

5. Damages module

Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. EPA's goal for this module is to evaluate the large increase in research on climate impacts and damages in the time since the models underlying the IWG methodology to date were published. The damages module in this draft report relies on three damage functions to synthesize the existing literature. They are:

- *a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),*
- *a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert et al. 2022b)), and*
- *a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).*

Each of the three damage functions is separately estimated in combination with the socioeconomics, climate, and discounting modules. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods. GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE

and DSCIM are not included in Howard and Sterner's (2017) final sample of studies. In Section 4.1 of the draft report, EPA combines the multiple lines of evidence on damages by averaging the results across the three damage module specifications to present SC-GHG estimates for a given range of discount rates.

- a. Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

The current damage modules represent a significant improvement over the damage functions in DICE, FUND and PAGE for two reasons: they are based on more recent studies than the studies underlying DICE 2013, FUND and PAGE, and the three damage modules represent independent sources of information. The damage function in DICE 2013, FUND and PAGE used in the previous SCC were not independent sources of information.

The DSCIM estimates are based on extensive, original empirical work, at a fine spatial scale. The GIVE model relies on other well-regarded published studies. Howard and Sterner is a meta-analysis of both top-down and bottom-up damage studies. The use of all three sources of damages strengthens the results.

- b. Does the draft report's use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes to you recommend? Do you think that there is a better approach for this update?*

I have no further changes to suggest.

- c. For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.*

None.

- d. Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.*

None.

- e. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?*

None.

f. Do you have longer-term recommendations for improvements to this module in future updates?

When the climate module is able to produce estimates of precipitation and extreme weather events, damages associated with flooding will need to be included. As the report itself notes, there are many categories of damages, including tipping points (see Table 3.2.1).

6. Discounting module

The discounting module used in the draft report relies on a set of calibrated dynamic discount rates. These rates were developed using a Ramsey discounting approach that endogenously connects the discount rate and socioeconomic scenarios where the Ramsey formula parameters are empirically calibrated to match near-term consumption interest rates and reconcile long-run interest rate behavior and economic growth uncertainty consistent with the RFF-SPs. Uncertainty in the starting rate is addressed by using three near-term target rates – 1.5, 2.0, and 2.5% - based on multiple lines of evidence on observed interest rate data.

a. Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?

When discounting climate damages, it is important to allow for the correlation between damages and the rate of growth in the economy—i.e., to allow for systemic risk (see, e.g., Gollier, *AEA Papers and Proceedings* 2014). Using constant exponential discounting does not allow for this. The consequences of ignoring the correlation between economic growth and damages have been illustrated in the RFF Brookings Paper https://www.brookings.edu/wp-content/uploads/2021/09/15985-BPEA-BPEA-FA21_WEB_Rennert-et-al.pdf

When there is considerable uncertainty in damages, failure to allow for this correlation can (incorrectly) increase the SCC by a factor of 10.

b. Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.

I would not consider alternative approaches.

c. Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.

The advantage of the current calibration of Ramsey discounting is that it links the initial discount rate to market rates of interest. The US government has always adhered to a

positive, rather than a normative, approach to discounting. This helps to preserve this approach, while allowing for the correlation described in Comment a.

- d. *Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?***

None.

- e. *Do you have longer term recommendations for improvements to this module in future updates?***

None.

6. Other

- a. *Accounting for risk aversion:***

- i. *Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?***

The current approach more adequately captures risk preferences than the previous ad hoc adjustment of constant exponential discount rates and the focus on the 95th percentile of the SCC. The discussion of risk aversion in the current draft is excellent.

- ii. *Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.***

None.

- iii. *Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?***

As noted above, the discussion of the current parameterization of η is very clear and I agree with the current choices.

- iv. *Do you have longer run recommendations for improved ways to account for risk aversion in future updates?***

None.

b. Characterization of distributional impacts and other presentational recommendations for the draft report:

- i. Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?***

The DSCIM authors have made the spatial distribution of climate damages (e.g., for mortality, energy consumption) clear in their published work. I think it is fine to refer to the reader of the TSD to these papers.

- ii. Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?***

In section 1.2, the report does note the NRC arguments for looking at global damages, even if one is interested only in impacts on the US.

- iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?***

None.

- c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?***

No further comments. This is an excellent report.

III. SPECIFIC OBSERVATIONS

No comments provided.

Karen Fisher-Vanden, PhD

Peer Review Comments on the TSD: Social Cost of Greenhouse Gas

Karen Fisher-Vanden, PhD

I. GENERAL IMPRESSIONS

(NOTE: As requested by the USEPA at the second meeting, I have attempted to distinguish between comments that should be addressed in the current report (“**SHORT-TERM**”) and comments that should be considered in a future report (“**LONG-TERM**”))

The approach taken to generate SC-GHG estimates is well-designed and executed and the document is well-written and easy to follow, although missing key details (as I describe below in my detailed comments). The modeling framework holds together well, and many choices made are defensible and based on current science.

Some larger issues I see, which are elaborated further below under specific sections, are:

- (**SHORT-TERM**): A significant amount is left out of the analysis that could move the SC-GHG estimates in either direction. Throughout the report, the explanation that an approach satisfies the National Academy report’s recommendation is used to justify methodological choices but is not very satisfactory. The report should be more transparent about the tradeoffs and how shortcomings of their methodological choices would bias the SC-GHG estimates. In particular, the analysis leaves out feedbacks, interactions, and other important considerations like intra- and international trade that will bias the results.
- It is well-understood that far future damage estimates are very likely to be off and it is difficult to judge whether the right estimate would be higher or lower. It isn't all about growth uncertainty but ability to adapt and vulnerability in a richer world. The authors attempt to address this by having income influence the damage estimates, but this seems too simplistic since there will likely be constraints on populations’ ability to adapt (e.g., island nations). The analysis also does not explicitly (but perhaps implicitly?) consider geoengineering options. Related, a world with climate change will be different and preferences will be very different as a result. (**SHORT-TERM**): It would be useful for the report to discuss what is explicitly and implicitly captured in this regard and how it would bias the estimates. (**LONG-TERM**): In a future report, it would be important to incorporate these omitted constraints into the estimates.
- (**LONG-TERM**): Although I completely understand and appreciate the choice to go with a modular approach, it comes with trade-offs. The only models that can be swapped in are those that are structurally the same. This doesn't allow for innovation on the modeling side to capture feedbacks and processes better since they would encapsulate many steps in the causal chain.

(SHORT-TERM/LONG-TERM): In the spirit of transparency, I would recommend some discussion in the report on the process for updating these estimates going forward; in particular, a discussion about how new science and approaches (outside of the current approach) will be incorporated into future estimates, and how other research communities can participate in the process going forward. I noticed that some of the same people who participated in the National Academy recommendations were also those who generated these new SC-GHG estimates. Although what the authors have done here is scientifically sound, a different set of people may have taken a different approach. From the few public comments that I have read, there is a distinct feeling that certain people and communities who have expertise to offer were shut out of the process which would be important to address.

- **(SHORT-TERM):** As elaborated below, a technical document that accompanies this report is needed so readers don't have to access, read, and knit together all of the cited documentation to fully understand what was done to generate these estimates.
- **(SHORT-TERM):** It might be useful to add a section that identifies important future research that is needed to improve the current estimates. This could provide a valuable research agenda for researchers in this field.

II. RESPONSE TO CHARGE QUESTIONS

1. *Use of a modular approach to the methodological updates*

Consistent with the National Academies' near-term recommendations, EPA separately updates the methodology in each step of the SC-GHG estimation—socioeconomic and emissions projections, climate science, economic damages, and discounting— increasing transparency and ease of updating each component to reflect the latest expertise from the scientific disciplines relevant to that component. Using this modular approach, EPA updated each step in SC-GHG estimation to improve consistency with the current state of scientific knowledge, enhance transparency, and allow for a more explicit representation of uncertainty.

- a. *Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

(LONG-TERM): Although making the modeling framework modular can, in principle, allow for the ability to “plug and play” any alternative socioeconomic, climate, or damage model based on new science, the reality is that the only models that can be swapped in are like-minded models that take in the same inputs and generate the same outputs. It doesn't allow for new science on the integration of modeling components that can capture key feedbacks, dynamics, and interactions across submodels. The integrated assessment modeling community and the multisector dynamic community have a lot to offer in terms of new science in this area.

It should be noted that to capture feedbacks and interactions, it is not enough to just iterate across the four modules (socioeconomics, climate, damages, discounting) since this will not capture integrated impacts—the fact that impacts in one sector will affect impacts in another sector—e.g., sectors competing for the same scarce water.

This and the NASEM report both highlight the shortcomings of the previous IWG modeling approach as motivation for the approach that was taken in these new SC-GHG estimates. I don't disagree with the points made in these reports. However, there are other integrated modeling approaches that could have been used and weren't. There are obvious trade-offs between approaches, and it would be important to explain these trade-offs. From my read of it, the authors have given more weight to the importance of modularity (to allow for easy updates on the individual components) and improving the representation of uncertainty. In doing this, however, they are giving less weight to capturing feedbacks and interactions and providing sectoral and regional detail to understand distributional effects. **(SHORT-TERM)**: In this report, it would be important to discuss how these choices and omissions bias the SC-GHG estimates.

b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?

The report provides a very nice description and overview, but I found myself having to read a number of papers provided in citations or on websites to truly understand what was done and how the different pieces connected. For instance, how the RFF-SP socioeconomic projections were constructed and then fed into the damage models such as DSCIM was not explained well. From reading the DSCIM user manual, I now realize that the DSCIM estimates were based on SSPs and RCPs and in order to connect to the RFF-SPs, the authors were required to construct a weighted average of SSP projections to replicate a particular RFF-SP projection. Thus, it isn't the case that the RFF-SPs are direct inputs to the DSCIM estimates. This was not clear in the report and is an important point since this approach could create consistency issues (as I discuss below in the damages module section). I wouldn't have known this if I had not consulted other sources of information. (Note: It is unclear to me whether enough time was provided for the review panel to read and comprehend all of the necessary supporting documentation before commenting on the scientific soundness of some of these estimates).

(SHORT-TERM): Therefore, this report is excellent for providing an overview, but not appropriate for trying to understand and comment on what is going on under the hood. A much more detailed technical document, similar to the DSCIM user manual, for instance, should accompany this report.

c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.

(LONG-TERM): Similar to how this report used alternative damage function models, EPA could also offer SC-GHG estimates based on fully integrated modeling.

(SHORT-TERM): Even though the authors leave this as a ‘long-term goal’ in SC-GHG estimation, at a minimum, the authors should attempt to measure and discuss how leaving out the integration and feedbacks would bias the SC-GHG estimates since these current estimates will likely be used for many years.

(SHORT-TERM): It would also be useful for the report to explain how new science will be incorporated into future SC-GHG estimates. What will the process be for this? Will it rely on updates from the teams already in place?

- d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?*

(LONG-TERM): Explore the generation of alternative estimates based on new fully integrated modeling efforts that are being done outside of the IWG efforts.

2. Socioeconomic and emissions module

The socioeconomic and emissions module used in the draft report relies on a new set of socioeconomic and emissions projections developed under the Resources for the Future Social Cost of Carbon Initiative (collectively referred to as the RFF-SPs) (Rennert et al. 2022a). The RFF-SPs are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO₂, CH₄, and N₂O) to 2300 that were generated using statistical and structured expert judgement methods and accounting for future policies and interdependencies. The country-level population projections extend the fully probabilistic statistical approach used by the United Nations for official population forecasts, while incorporating improvements recommended by a panel of expert demographers (Raftery and Ševčíková 2021). The country-level empirical economic growth projections (Müller, Stock, Watson 2020) were extended in time using expert elicitation (Rennert et al. 2022a). The emissions projections are conditioned on future economic growth and a reflection of an “Evolving Policies” case (Rennert et al. 2022a).

- a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?*

The reasoning given for generating new scenarios using the methodology of the RFFSPs is related to the need to better represent the far future and to generate probabilistic long-run projections of population and economic growth, which was missing with the SSP/RCP scenarios. To address these needs, the RFF-SPs apply the Muller, Stock, and Watson (2022) approach which is based on convergence in economic growth theory to generate a set of probabilistic GDP projections. Therefore, my understanding is that future economic growth is driven by assumptions made about the speed of convergence of individual economies and their influence on the convergence of other economies with similar characteristics. The RFF-SPs then use expert elicitation (from a panel of macro growth economists) to extend the projections to 2300. **(LONG-TERM):** Although this

approach does address some of the important shortcomings of the IWG approach as identified in the NASEM report, it creates others that suggests a hybrid approach (e.g., one that combines growth projections with structural modeling) may be warranted:

- **(LONG-TERM):** How do these RFF-SP projections ensure plausibility without some connection to structural models? That is, are the large structural changes that would have to occur in many lesser developed countries to reach convergence feasible? To assess this, you would need to know the structure and characteristics of the current economy and what structural changes would need to occur. In many instances, I presume, this may not be feasible based on fixed factors, technology, and other country-specific characteristics and endowments. In the construction of the SSP/RCP scenarios, structural economy-wide models helped identify and shape the set of scenarios by pointing out where certain pairings would not be possible—e.g. certain RCPs were not achievable with certain SSPs without an infeasible set of technologies. We could be seeing a similar problem here with the use of these RFF-SPs. **(SHORT-TERM):** This report should discuss whether this could be an issue with the estimates presented in the report.
- **(LONG-TERM):** This approach also does not account for international trade implications of impacts which will be substantial and are not captured in the current SC-GHG estimates. Trade is an important part of the story here and isn't captured. If impacts are spatially heterogenous (which we know they are), then comparative advantage can switch to countries that are impacted less, thus mitigating impacts in those countries through increased competitiveness. This approach is also unable to capture supply chain issues. This provides another argument for incorporating economy-wide models with sectoral and international trade detail. **(SHORT-TERM):** The report should discuss how the SC-GHG estimates would be different if trade was captured.
- **(LONG-TERM):** Importantly, the RFF-SP approach is not set up well for incorporating feedbacks from the damage modules and interactions across impacts. DSCIM, for instance, generates fine-scale dose-response functions by sector which could easily be incorporated into structural economy-wide models with spatial and sectoral detail. Not only would it allow for feedbacks, it would also allow for the explicit representation of integrated impacts, rather than modeling impacts separately for each sector. It isn't clear how this could be done with the RFF-SP model. As argued in the DSCIM description, it is important to estimate impacts at the fine scale and then aggregate up. Thus, it would also be important to capture feedbacks and interactions at the fine-scale and aggregate up. **(SHORT-TERM):** The report should include some discussion of how these feedbacks and interactions could be captured with the current approach.
- **(LONG-TERM):** Should the SC-GHG estimates capture distributional impacts somehow? If so, this doesn't seem possible with the current socioeconomic approach. **(SHORT-TERM):** The report should discuss whether this will be possible with the current approach and if so, how.

- The RFF-SPs capture one type of uncertainty, from what I can tell. (I had to read Rennert et al, 2021 to understand this since the EPA Supplemental document does not provide details). They are capturing uncertainty by using expert elicitation where “experts provided their 1st, 5th, 50th, 95th, and 99th quantiles for the variables of interest: levels of OECD GDP per capita for 2050, 2100, 2200, and 2300” (Rennert et al, 2021) to “modify econometric projections of GDP per capita based on the MSW (2019) methodology and generate density functions of internally consistent projections of economic growth at the country level.” Thus, the uncertainty captured is uncertainty related to speed of convergence (how far a country is from the frontier), I believe. **(LONG-TERM)**: The current approach does not capture uncertainty related specifically to technological change, population growth, changes to the energy system, etc, or structural uncertainty related to how factors/sectors interact. Rather it is implicit in an expert’s opinion on growth in GDP per capita in OECD countries. Again, this was an approach that was chosen by the authors that addresses some shortcoming from previous approaches but creates others. (How come the expert elicitation panel did not include experts involved in the SSP scenarios? These people have a lot to offer to this process). **(SHORT-TERM)**: The report should be more forthcoming on the types of uncertainty that are being captured and the types of uncertainty that are not, with a discussion of the magnitude and direction of the uncertainties that are left out.

(LONG-TERM): Therefore, an alternative approach may be to combine the growth modeling approach of MSW (used in the RFF-SPs) with the structural modeling, say, done by the IPCC economy-wide models (NOT the aggregate IWG models) in order to ensure that these economic growth projections are plausible and, to be clear to consumers of these estimates what these growth projections imply for the structure of individual countries in order to generate such growth projections. (This was a strength of the SSPs). This will be important for the damage estimates especially since some of these damage functions were estimated based on SSP/RCPs. It is also important for capturing interactions and feedbacks since economy-wide models are well-equipped to incorporate damage feedbacks.

- b. *Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages of these approaches.***

(SHORT-TERM/LONG-TERM): For comparison, why not use the SSP/RCPs scenarios as was used by the DSCIM team to generate their damage estimates instead of the RFF-SPs to see what difference it would make in the SC-GHG estimates?

- c. *Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?***

(SHORT-TERM): As mentioned prior, this is another instance of having to read a number of other papers in order to fully understand what was being done. Please supply a technical document to accompany the report.

- d. *Do you have longer-term recommendations for improvements to this module in future updates?*

See comments under a.

3. *Climate module*

EPA's goal for this update of the climate module was to adopt a widely used, transparent climate model that could reflect the latest scientific understanding of the relationships between CO₂ emissions, atmospheric CO₂ concentrations, and global mean surface temperature change (and any other climatic variables required as inputs to the damage module) over time while accounting for non-CO₂ forcing and allowing for the evaluation of uncertainty. The climate module used in the draft report relies on the open source and widely used Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature change. The estimates presented in the report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b), in which the uncertain parameters have been calibrated to be consistent with the most recent assessment of the IPCC, such as the IPCC AR6 assessed likely range of 2.5 to 4°C for the equilibrium climate sensitivity.

- a. *Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?*

(LONG-TERM): It seems important for the climate module to capture precipitation and not just temperature, which is a shortcoming of the current approach. My understanding, though, is that this was done because the damage functions are only based on temperature and not precipitation which is a shortcoming of these damage functions.

- b. *Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.*

I defer to others on the review panel who are better equipped to comment on this.

- c. *Are there other models/methods for projecting sea level impacts resulting from*

temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.

I defer to others on the review panel who are better equipped to comment on this.

- d. Do you have recommendations for strengthening the presentation of this module, g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?*

I defer to others on the review panel who are better equipped to comment on this.

- e. Do you have longer-term recommendations for improvements to this module in future updates?*

(LONG-TERM): This module must include precipitation and the damage functions must be able to take this important climate variable into account.

4. Damages module

Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. EPA's goal for this module is to evaluate the large increase in research on climate impacts and damages in the time since the models underlying the IWG methodology to date were published. The damages module in this draft report relies on three damage functions to synthesize the existing literature. They are:

- a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),*
- a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert et al. 2022b)), and*
- a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).*

Each of the three damage functions is separately estimated in combination with the socioeconomics, climate, and discounting modules. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods. GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE and DSCIM are not included in Howard and Sterner's (2017) final sample of studies. In Section 4.1 of the draft report, EPA combines the multiple lines of evidence on damages by averaging the results across the three damage module specifications to present SC-GHG estimates for a given range of discount rates.

- a. *Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

The damages module in this report is an improvement over the IWG methodology in that it captures updated science (and numerous new studies) on measuring and monetizing impacts including regional and sectoral disaggregation and coverage, and greater use of empirical evidence. However, these approaches have some drawbacks:

- **(LONG-TERM)**: Sectoral damages do not feedback to the socioeconomic module, which will affect economic growth and thus emissions and ultimately damages. As argued in this section of the report, it is important to estimate impacts at the fine scale and then aggregate up. Thus, it would also be important to capture feedbacks and interactions at the fine-scale and aggregate up. **(SHORT-TERM)**: The report should discuss how leaving out these feedbacks would bias the SC-GHG estimates.
- **(LONG-TERM)**: All of the damage function approaches considered in both the IWG and this report estimate sectoral and regional damages separately and do not consider integrated impacts (the fact that impacts in one sector or region could influence impacts in another sector or region), indirect sectoral impacts, or trade implications which could alleviate or exacerbate these estimates. **(SHORT-TERM)**: This report should include a discussion of how modeling sectoral impacts separately would bias the SC-GHG estimates.
- Damage functions are functions of temperature and not other climate variables such as precipitation and extremes which are key to impacts. **(LONG-TERM)**: Future estimates should address this issue. **(SHORTTERM)**: This report should discuss how this omission would bias the SCGHG estimates.

Also potentially problematic is the lack of a direct connection between the RFF-SPs and damage functions. For instance, the DSCIM estimates were based on SSPs and RCPs and in order to connect to the RFF-SPs, the authors were required to construct a weighted average of SSP projections that most closely resemble each RFF-SP projection. Thus, it isn't the case that the RFF-SPs are direct inputs to the DSCIM estimates. I believe this could bias the damages results if there are nonlinearities in the inputs to the damage function since you are taking weighted averages of multiple SSPs that individually could be much different from each other. **(LONG-TERM)**: The socioeconomic or damage module should be revised so there is a direct connection. This highlights the potential issues that can arise with the modular approach—there needs to be consistency on the outputs and inputs between two connected modules. **(SHORT-TERM)**: The report should assess and discuss the implications of the weighted average scenarios approach taken for the damage estimates.

(LONG-TERM): Another reviewer on the panel made the excellent point that it is

important to recognize and capture the fact that damages will affect utility through different channels. This point underscores the importance of structural modeling that can capture these different channels.

(SHORT-TERM): Additional point: How useful is it to estimate impacts of far future temperature on energy consumption, labor, and agriculture? We will be in a completely new energy and industrial world at that point. This should be discussed in the report.

- b. Does the draft report's use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes to you recommend? Do you think that there is a better approach for this update?***

There are a number of integrated modeling studies that examine fine-scale impacts as part of the integrated assessment and multisector dynamics modeling communities, although this work is focused on providing fine scale analysis rather than aggregate damage functions. Please see, for instance:

<https://climatemodeling.science.energy.gov/program-area/multisector-dynamics>

- c. For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.***

See comment in b.

- d. Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.***

(LONG-TERM): Indirect impacts and integrated impacts are very important and not considered in this report.

- e. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?***

(SHORT-TERM): As mentioned above, this report is excellent for providing an overview, but not appropriate for trying to understand and comment on what is going on under the hood. A much more detailed technical document, similar to the DSCIM user manual, for instance, is needed.

- f. Do you have longer-term recommendations for improvements to this module in future updates?***

See comments above.

5. *Discounting module*

The discounting module used in the draft report relies on a set of calibrated dynamic discount rates. These rates were developed using a Ramsey discounting approach that endogenously connects the discount rate and socioeconomic scenarios where the Ramsey formula parameters are empirically calibrated to match near-term consumption interest rates and reconcile longrun interest rate behavior and economic growth uncertainty consistent with the RFF-SPs. Uncertainty in the starting rate is addressed by using three near-term target rates – 1.5, 2.0, and 2.5% - based on multiple lines of evidence on observed interest rate data.

- a. Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?*

The Ramsey formulation adopted in this section is an improvement over past discounting approaches, in my opinion since it allows for dynamic discount rates and long-term intertemporal trade-offs which is key to the climate change issue.

What is interesting, though, is that the discount rates generated from this approach are not that far off from discount rates used in the IWG, although in this approach, discount rates fall slightly over time and uncertainty ranges include significantly higher and lower discount rates.

- b. Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.*

I defer to others on the review panel who are better equipped to comment on this.

- c. Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.*

I defer to others on the review panel who are better equipped to comment on this.

- d. Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?*

Unlike some of the other sections of the report, I felt like this section did a better job providing the details needed to understand what was being done, although I did end up reading some of the cited articles to get a fuller understanding of the approach and calibration.

- e. *Do you have longer term recommendations for improvements to this module in future updates?*

I defer to others on the review panel who are better equipped to comment on this.

6. *Other*

- a. *Accounting for risk aversion:*

- i. *Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?*

I believe the methodological approach to account for risk aversion is consistent with the discounting approach and an improvement over past studies.

- ii. *Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.*

I defer to others on the review panel who are better equipped to comment on this.

- iii. *Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?*

This section, in contrast with other sections, was better at being transparent and forthcoming with the biases to the SC-GHG estimates resulting from their choice of parameter values (e.g., bottom of pages 64 and 65). This type of transparency is needed throughout the report.

- iv. *Do you have longer run recommendations for improved ways to account for risk aversion in future updates?*

I defer to others on the review panel who are better equipped to comment on this.

- b. *Characterization of distributional impacts and other presentational recommendations for the draft report:*

- i. *Given the spatial resolution available in the modeling performed for this update, do*

you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?

The DSCIM damage estimates are done at a very fine spatial scale and would allow for distribution impacts to be captured if integrated into the right socioeconomic model. As I recommend above in section 2a., this provides further support for taking a hybrid approach with the socioeconomic projections since the structural economy-wide models are becoming finer scale (even down to the country level) to allow for these types of distributional effects to be captured.

(LONG-TERM): it will be important in future SC-GHG estimates to capture feedbacks, interactions, and intra- and international trade to truly capture the distributional impacts of climate change. There are plenty of studies that have shown the importance of this.

- ii. Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?***

(SHORT-TERM): Again, reading other documentation was essential to being able to understand this. The report does not provide enough detail.

- iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?***

See above.

- c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?***

(LONG-TERM): The point was raised in the second meeting (and in the report) that it is important to capture global impacts since there are spillovers (and not to take a partial “only damages to the US” approach when generating the SC-GHG estimates). I agree but wonder how this would be captured without the explicit modeling of trade, as discussed above in my comments.

III. SPECIFIC OBSERVATIONS

No comments provided.

Chris E. Forest, PhD

Peer Review Comments on the TSD: Social Cost of Greenhouse Gas

Chris E. Forest, PhD

I. GENERAL IMPRESSIONS

The update to the Social Cost of Greenhouse Gas Estimates is a significant step towards addressing the National Academies report in 2017 and continuing to improve the ability to assess the impact on the United States. I am very happy to see the separate discussions on the four modular components provides sufficient material for the EPA to move forward and adopt the additional changes. The new material and descriptions of updates in all modules include significant advances. The new materials have generally come from peer-reviewed research papers and the materials being provided by through both academic and research organizations addressing these critical issues.

I found the material to be very straight forward and easy to follow, despite the long footnotes, and recognize the differences between the academic research papers and the style of the EPA/government documents. The use of itemized lists helps present the key updates such that readers can scan the document and easily identify the key findings in each section. This should be done in each section if possible. The use of key tables and figures are adequate to convey the content related to the primary updates.

As a committee member of the National Academies (2017) report, collectively, the new advances across all the subjects had significant updates. The science and economics are continuing to mature, and the low-hanging fruit are few, while we're now picking from higher up in the trees. This continual upgrade and revisions process is an important component of this latest update to the Social Cost of Greenhouse Gas Estimates. The National Academies (2017) report provided questions to answer, and this report identifies where most of these have been answered. To me, of the four components, the comprehensive update of the damage estimates is the newest part of the work and provides a major component that fits well with the other modules. The update to the damage module will need to be reviewed and revisited once the final version is completed.

II. RESPONSE TO CHARGE QUESTIONS

1. *Use of a modular approach to the methodological updates*

Consistent with the National Academies' near-term recommendations, EPA separately updates the methodology in each step of the SC-GHG estimation—socioeconomic and emissions projections, climate science, economic damages, and discounting— increasing transparency and ease of updating each component to reflect the latest expertise from the scientific disciplines relevant to that component. Using this modular approach, EPA updated each step in SC-GHG estimation to improve consistency with the current state of scientific knowledge, enhance transparency, and allow for a more explicit representation of uncertainty.

- a. *Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG*

estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?

Yes, the modular approach works well, with the caveat that as finer scale information will eventually be added into more than one module and this will add another layer of complexity. In the long run, new tools will be required to improve the sampling strategies across all modules to estimate the final distributions of the SC-GHG.

b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?

Yes, the modular approach is clear for me. I have no specific recommendations at this time.

c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.

To keep the modular paradigm/structure, I am advocating for more creative opportunities to incorporate climate/weather extremes into all modules when running an instance of the full model. Each module has some connections to the climate data that drives emissions, the current observed climate pathways (given the uncertainty in projections based on historical records), and the impacts estimates. I am not clear yet, on how the discounting might be connected to climate, but one relevant idea is that people's preferences are psychologically connected to higher anxiety about the "current" climate trajectory. In turn, this would imply a stronger sense of urgency that would increase the value of the long-term future.

With a view towards sensitivity testing of the SC-GHG modules, I advocate to use stratified or direct sampling methods that allow accounting for the modules as well as the internal parameters within the modules. Variants of Latin Hyper-Cube Sampling strategies (or similar tools) or methods of deep uncertainty quantification (e.g., Oddo et al. 2017, doi:10.1111/risa.12888) should be considered as model complexity increases.

d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?

The only significant alternative would be to do a full Monte Carlo Sampling strategy with multiple millions of simulations. This would allow running an $n=1000$ or larger stratified sampling approach (or if computing is available, a full random sampling with $n=10^9$) that could incorporate individual realistic futures to consider from high resolution Earth system models. This would lead to creating a 10+ year project to consider how to address the tails of the distribution.

2. Socioeconomic and emissions module

The socioeconomic and emissions module used in the draft report relies on a new set of

socioeconomic and emissions projections developed under the Resources for the Future Social Cost of Carbon Initiative (collectively referred to as the RFF-SPs) (Rennert et al. 2022a). The RFF-SPs are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO₂, CH₄, and N₂O) to 2300 that were generated using statistical and structured expert judgement methods and accounting for future policies and interdependencies. The country-level population projections extend the fully probabilistic statistical approach used by the United Nations for official population forecasts, while incorporating improvements recommended by a panel of expert demographers (Raftery and Ševčíková 2021). The country-level empirical economic growth projections (Müller, Stock, Watson 2020) were extended in time using expert elicitation (Rennert et al. 2022a). The emissions projections are conditioned on future economic growth and a reflection of an “Evolving Policies” case (Rennert et al. 2022a).

- a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?*

I would offer the discussion from Sarofim et al. (2021, <https://doi.org/10.1038/s41558-020-00973-9>) that advocates for a hierarchy of modeling paradigms which fits the needs of the research question. Depending on the outcomes of the climate model projections, the users may want to account more carefully for non-linear outcomes for specific projections or impacts. Ultimately, this requires using models that include such non-linear equations. If the high-impact tails of a distribution are critical to the specific costs entering into the SC-GHGs, additional research will be needed to assess the uncertainties in the climate response and climate impacts.

The typical example from the climate science arena would be to ask: How close are we to any tipping points within the Earth system? If yes, then the non-linearities have a critical role to play to assess the level of impacts. The natural emissions of carbon dioxide, methane, and nitrous oxide still have a role to play as feedbacks driven by the anthropogenic forcings.

- b. Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages of these approaches.*

This is not my area of expertise.

- c. Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?*

For the emissions model, specifically, we know that the emissions and sinks of methane are strongly dependent on climate variables such as temperature and precipitation within

the tropics and extratropics. For methane, the destruction rate of methane is a key issue and should be included in the models. While the heat-trapping gases will take multiple decades to impact temperature, the concentrations of nitrous oxide and methane can have immediate impact on air quality and thus, have direct impacts on human health and on local ecosystems when they are emitted. To better understand these impacts, we need to incorporate the secondary effects of the GHGs that contribute to the damage estimates, which could help clarify how these effects add to the Social Costs or to identify what processes could be missing.

While not explicitly having specific suggestions on the socioeconomic module, we know that climate change can have direct and indirect effects on the socioeconomic activities. **From a communication perspective, we should develop storylines to explain both direct and indirect interactions of the socio-economic and emissions model with the other modules.** Within the context of SC-GHG, we should use such storylines to help the public and the private sector improve communications and clarify many of the subtler issues as research continues to improve these tools. While we have a clearer understanding of how climate change is driven by emissions, we must also create clearer messages on how feedbacks from climate change are similarly driving changes in both socio-economic factors and emissions.

d. Do you have longer-term recommendations for improvements to this module in future updates?

My long-term suggestions are most relevant for natural emissions being driven by the future climate changes that would add additional feedbacks on both climate impacts and on climate change itself. The ability to assess these feedbacks will be critical and then, we must feed the natural emissions into both the climate module and the impacts module as well would be useful.

3. Climate module

EPA's goal for this update of the climate module was to adopt a widely used, transparent climate model that could reflect the latest scientific understanding of the relationships between CO₂ emissions, atmospheric CO₂ concentrations, and global mean surface temperature change (and any other climatic variables required as inputs to the damage module) over time while accounting for non-CO₂ forcing and allowing for the evaluation of uncertainty. The climate module used in the draft report relies on the open source and widely used Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature change. The estimates presented in the report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b), in which the uncertain parameters have been calibrated to be consistent with the most recent assessment of the IPCC, such as the IPCC AR6 assessed likely range of 2.5 to 4°C for the equilibrium climate sensitivity.

a. Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG

methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?

Yes, this update provides an improved representation of the climate response to the net radiative forcing based on the accumulation of GHGs in the atmosphere and ocean. The testing of the Reduced-complexity Climate (RC) models has been tested against IPCC-class Earth System Models. Developers of all three models (FAIR1.6.2, MAGICC7, and HECTOR2.5) are participating in the IPCC RCMIP (Nicholls, Z. R. J., et al., 2020, <https://doi.org/10.5194/gmd-13-5175-2020>). The goals of the RCMIP project are to be able to assess the perturbation between the reference scenario and a perturbed scenario to determine the additional global warming associated with the perturbed forcing. This perturbation is fed into the climate impacts module to estimate the climate impact damages. Based on the RCMIP results, these three models have the necessary components to estimate the global mean temperature that can be used in the RC module.

- b. Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.***

Higher order complexity models are available and should be considered to benchmark the RC models. Despite the computational costs Notwithstanding can be prohibitive, we should be testing “state of the science” models now that improve our level of understanding for regional climate changes.

- c. Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.***

I am only familiar with the two sea-level models in this report at this time.

- d. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?***

Based on the RCMIP work (Nicholls et al. 2020), I would consider figures to develop storylines of the trade-off between ocean carbon and heat uptake and the surface warming due to the GHGs. Additionally, we need to better describe uncertainties of the trade-offs between surface warming and net radiative forcing. These may be technical issues, but users might understand that if the ocean is not warming quickly, then the land/ocean surface must be warming faster.

- e. Do you have longer-term recommendations for improvements to this module in future***

updates?

The ability to sample the transient climate response and the sea level changes are the key elements in the current RC models until moving to more comprehensive models. I am concerned that “solar radiation reduction” could be a realistic scenario that might not be modeled well with the current modeling systems.

4. Damages module

Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. EPA’s goal for this module is to evaluate the large increase in research on climate impacts and damages in the time since the models underlying the IWG methodology to date were published. The damages module in this draft report relies on three damage functions to synthesize the existing literature. They are:

- *a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),*
- *a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF’s Social Cost of Carbon Initiative (Rennert et al. 2022b)), and*
- *a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).*

Each of the three damage functions is separately estimated in combination with the socioeconomics, climate, and discounting modules. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods. GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE and DSCIM are not included in Howard and Sterner’s (2017) final sample of studies. In Section 4.1 of the draft report, EPA combines the multiple lines of evidence on damages by averaging the results across the three damage module specifications to present SC-GHG estimates for a given range of discount rates.

- a. Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

Yes, this update provides a better general estimate of the damages than a few functional representations in the original models. While these are more comprehensive, they are most likely to be underestimating damages if smaller sectors are left out.

- b. Does the draft report’s use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes to you recommend? Do you think that there is a better approach for this update?*

At this time, the damage function module is in a state of flux as more damages are identified and not yet in the literature. So, it's a moving target and will most likely always be an underestimate.

- c. For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.*

N/A.

- d. Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.*

N/A.

- e. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?*

Not at this time.

- f. Do you have longer-term recommendations for improvements to this module in future updates?*

The major advances must include more comprehensive impacts that will eventually need to be derived from higher complexity earth system models.

5. Discounting module

The discounting module used in the draft report relies on a set of calibrated dynamic discount rates. These rates were developed using a Ramsey discounting approach that endogenously connects the discount rate and socioeconomic scenarios where the Ramsey formula parameters are empirically calibrated to match near-term consumption interest rates and reconcile long-run interest rate behavior and economic growth uncertainty consistent with the RFF-SPs. Uncertainty in the starting rate is addressed by using three near-term target rates – 1.5, 2.0, and 2.5% - based on multiple lines of evidence on observed interest rate data.

- a. Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?*

Not at this time.

- b. *Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.***

Not at this time.

- c. *Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.***

Not at this time.

- d. *Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?***

Not at this time.

- e. *Do you have longer term recommendations for improvements to this module in future updates?***

Not at this time.

6. Other

- a. *Accounting for risk aversion:***

- i. *Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?***

No comment.

- ii. *Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.***

No comment.

- iii. *Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the***

parameterization and implementation with the damage functions used in this update?

Not at this time.

- iv. Do you have longer run recommendations for improved ways to account for risk aversion in future updates?***

The psychological and behavioral sciences will need to be considered to address long-term risks. The mainstream discussions of observed climate changes based on the historical climate records does not fully account for the radiative forcing due to the emissions in the last few decades. The current younger generations will be experiencing the climate change from the accumulated forcing from the past 30-40 years. The assessments of risk aversion should be stratified by age and use tools such as the assessment “Global Warming’s Six Americas” from the Yale Program on Climate Change Communication. Other global projects to assess risk aversion through surveys need to be considered on this topic.

- b. Characterization of distributional impacts and other presentational recommendations for the draft report:***

- i. Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?***

Improvements will need to use existing weather and climate models and identify how resolution is currently limiting the evaluation of extreme events. Emulators of weather extremes are new and valuable tools that are more available in the insurance industry (aka catastrophe models). Precipitation and wind extremes are not resolved at scales that are not in any current regional or global models. The development of these tools in the environmental modelling research area are only now becoming available.

An additional component is how to extract information for damage functions that are not explicitly modeled. The non-linear models will need multiple inputs (e.g., wind, humidity, air quality, temperature, etc.) that are currently being developed for individual cities. A comprehensive assessment probability functions are not capable to capture the concurrent extremes that would require more than one from the long list of inputs.

- ii. Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?***

While it is not my expertise, I support improvements in the estimation approaches that would address how to provide global SC-GHG estimates that could influence economic damages through global mechanisms like supply chains or pandemics.

iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?

Not at this time.

c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?

My co-evaluators emphasized that the current SC-GHGs is only a partial estimate. By recognizing this, we must put more effort to understand the global response to climate change damages that will be influencing all regions of the world (populated or not). We need to develop additional metrics to account for the non-US impacts and damages. From the climate science side, this will require improving the impacts and damage estimates for all parts of the world and would require specific IPCC research agendas to develop and account for the full global estimates of Social Costs of Greenhouse Gases among all countries.

III. SPECIFIC OBSERVATIONS

No comments provided.

Catherine Louise Kling, PhD

Peer Review Comments on Aluminum Criteria Model

Catherine Louise Kling, PhD

I. GENERAL IMPRESSIONS

This is a much-needed improvement in estimating the social cost of carbon and greenhouse gas emissions. The Agency is to be applauded for taking leadership in developing this critically needed new set of estimates. The document provides the basis for both an improved estimate to be used in rulemaking in the near term, as well as providing the core foundation for continuing refinements and improvements in the future. While I have a range of questions and suggestions for improvement, it is important to recognize the significant step forward the agency has taken with this first set of estimates of the Social Cost of GHGs.

The overall structure of the report is clear and the development of the modular approach as recommended by NASEM is well articulated. By establishing a modular platform, the Agency is well positioned to both improve the current set of estimates and allow for updates over time as the scientific and economic basis for the estimates evolve and improve.

Despite these strengths, there are shortcomings with the report in its current form. I begin with some overarching concerns and then address each of the charge question areas in more detail below.

1. My first reaction to the writing style and content was that it was not detailed enough to be adequate for detailed technical review. After the helpful Zoom with EPA staff, I better understand the intended audience. The current level of depth suits their intended purpose well. However, a great deal of the analysis to support the module development and the empirical estimates generated are not sufficiently documented for careful review. Perhaps it would be useful to make clear in the intro that the document is intended as a road map, and that by necessity many of the details and decisions are documented in supporting materials and the interested reader should look there. Another possibility is to provide technical appendices.

2. Definitions. The NASEM (2017) report was careful to define each term used throughout the report and to use them consistently. This report would be improved if it included a glossary of key terms. For example, the NASEM report defines the social cost of carbon as "...an economic metric intended to provide a comprehensive estimate of the net damages – the monetized value of the net impacts, both negative and positive – from the global climate change that results from a small (1 metric ton) increase in carbon dioxide emissions," (exec. summary p. 1). This report provides a similar, but not identical definition "the SC-GHG is the monetary value of the net harm to society from emitting a metric ton of that GHG to the atmosphere in a given year." Beyond the obvious extension to all GHGs (which is great), this report's definition does not clarify that the SC-GHG is a metric intended to provide a comprehensive estimate. The fact that it is intended to do so but does not yet achieve that goal due to many omitted components, is important for transparency and for explaining updates in the future. In addition to providing a comprehensive estimate of impact damages, I suggest making clear in the definition that the metric include both future and current

damages. Finally, the definition of the SC-CO₂ as developed in this document differs from the definition of SCC in the NASEM report as this new social cost incorporates multiple GHG emissions, both through their effect on climate and through direct externalities (positive or negative) on ocean acidification, etc. I suggest highlighting these advances early in the document.

3. To be clear, the report does a good job in many places of describing that there are many important omissions from the current estimates of this metric, but this is an important enough of a point that it would be valuable to articulate clearly and early. I suggest that in the introduction, executive summary, and summary the EPA state more explicitly that current estimates of the metric do not meet the full bar of the intention, that however this is a major step to improve these estimates. I hope that doing so early will add to transparency so that when the next update is introduced with different numbers and more modules, the IWG or EPA can point to the current document as having laid out the foundation that such updates are expected and desirable, rather than appearing idiosyncratic or worse yet, politically motivated.

Other useful definitions from the NASEM report include NASEM (2017) defined climate impacts as “the biophysical or social effects driven by climate change” and climate damages as the “monetized estimates of the social welfare effects” (p. 138 and elsewhere). Consistent use of terminology like this throughout would aid transparency.

4. In a number of places in the document the EPA reports that the estimates presented here are “conservative.” In some case this conservative (meaning lower bound?) estimate is explained as coming from omissions of information (like monetization of some damage impacts), in other cases, it is explained as an intentional effort to be conservative (also meaning to provide a lower bound?). The first issue is unavoidable and just needs more emphasis. I suggest explicitly using the words “lower bound” as “conservative” can have multiple meanings (e.g., if one were a proponent of the precautionary principle, conservative would mean use the highest damage estimate possible). The second issue is problematic for use of these metrics in benefit-cost analysis or any other economic efficiency interpretation. In general, if we are focusing on a single point in the SCC distribution for use in efficiency analysis, we should be trying to estimate the **mean willingness to pay** not percentile of the distribution that lies to the left. Inadequate attention to the economic welfare interpretations of the monetized damage components.

5. The report describes many places where the advice of NASEM (2017) was followed. That report was excellent and following their advice is great, but there are things that were suggested in that report that were not undertaken. A reader could easily believe otherwise (see Table 5.1 which lists the NASEM recommendations that were implemented but omits those that were not). For example, page 9 indicates that in the short run the IWG should, among other things... update the damages by presenting spatially disaggregated market and nonmarket damages by region and second in both monetary and natural units (incremental and total) little to none of this has been done. As I argue below the omission of natural unit impacts is particularly concerning given how much remains nonmonetized. This point does not undermine any of the value of these new numbers, the point is to be transparent about what these numbers represent and what they do not.

Equation 2.5.1 on page 62 provides something like this, but its variables are not defined (the use of Δ ! for “marginal damages” is confusing, is this defined in consumption of money?) and it does not discuss the aggregation component or the interpretation component.

II. RESPONSE TO CHARGE QUESTIONS

1. *Use of a modular approach to the methodological updates*

Consistent with the National Academies’ near-term recommendations, EPA separately updates the methodology in each step of the SC-GHG estimation—socioeconomic and emissions projections, climate science, economic damages, and discounting— increasing transparency and ease of updating each component to reflect the latest expertise from the scientific disciplines relevant to that component. Using this modular approach, EPA updated each step in SC-GHG estimation to improve consistency with the current state of scientific knowledge, enhance transparency, and allow for a more explicit representation of uncertainty.

- a. Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

As noted above, the move to a modular approach is highly valuable and sets the stage for continuing improvements. A suggestion for Figure 2.1 is to add a box coming from the damages module to represent unmonetized damages. Perhaps it would be “as yet unmonetized damages”? or something of that sort. Again, the goal is transparency and recognition of this omission.

- b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?*

See above.

- c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.*

No.

- d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?*

See above.

2. Socioeconomic and emissions module

The socioeconomic and emissions module used in the draft report relies on a new set of socioeconomic and emissions projections developed under the Resources for the Future Social Cost of Carbon Initiative (collectively referred to as the RFF-SPs) (Rennert et al. 2022a). The RFF-SPs are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO₂, CH₄, and N₂O) to 2300 that were generated using statistical and structured expert judgement methods and accounting for future policies and interdependencies. The country-level population projections extend the fully probabilistic statistical approach used by the United Nations for official population forecasts, while incorporating improvements recommended by a panel of expert demographers (Raftery and Ševčíková 2021). The country-level empirical economic growth projections (Müller, Stock, Watson 2020) were extended in time using expert elicitation (Rennert et al. 2022a). The emissions projections are conditioned on future economic growth and a reflection of an “Evolving Policies” case (Rennert et al. 2022a).

- a. *Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?*

The work developed by RFF and used to produce the socioeconomic and emissions projection is a significant improvement and to follow the recommendations of NASEM (2017) well.

- b. *Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages of these approaches.*

None that I am aware of.

- c. *Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?*

This is a place where more details would be useful, especially more details about how the future climate scenarios were informed and altered by expert judgment. An important part of these projections is the advice from NASEM to take account of future emission policies and the consequences. Again, this is to be applauded, but documentation of how this was done, how big of an effect this component had should be discussed and documented. Visually demonstrating how much of an effect on the emissions stream the judgements on policy responses and adaptations would improve the transparency of the report. If possible, it would also be valuable to document/explain how much difference incorporating these policies induced changes made in the computation of the social cost estimates.

- d. *Do you have longer-term recommendations for improvements to this module in future updates?*

See above.

3. *Climate module*

EPA's goal for this update of the climate module was to adopt a widely used, transparent climate model that could reflect the latest scientific understanding of the relationships between CO₂ emissions, atmospheric CO₂ concentrations, and global mean surface temperature change (and any other climatic variables required as inputs to the damage module) over time while accounting for non-CO₂ forcing and allowing for the evaluation of uncertainty. The climate module used in the draft report relies on the open source and widely used Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature change. The estimates presented in the report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b), in which the uncertain parameters have been calibrated to be consistent with the most recent assessment of the IPCC, such as the IPCC AR6 assessed likely range of 2.5 to 4°C for the equilibrium climate sensitivity.

- a. *Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?*

This is outside my area of expertise.

- b. *Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.*

Again, outside of my expertise.

- c. *Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.*

Not that I am aware of.

- d. *Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to*

enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?

It would be helpful to a nonexpert (like me) to understand the baseline on which to consider the 1 GtC pulse of carbon dioxide. Is that a .001% pulse or more like a 5% pulse?

Figure 3.2 contains a list of the set of climate impacts that are not currently captured in the climate module. It would be useful to discuss the consequences of those omissions for the computation of the social cost of GHG estimates. Given that these climate impacts are not represented in this work, what does that imply for the damage estimates that cannot be included in the SC GHG estimates (such as the impacts of ocean acidification as explained on page 35).

e. Do you have longer-term recommendations for improvements to this module in future updates?

Continuing to focus on both physical and monetized impacts should continue to be prioritized in future updates.

4. Damages module

Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. EPA's goal for this module is to evaluate the large increase in research on climate impacts and damages in the time since the models underlying the IWG methodology to date were published. The damages module in this draft report relies on three damage functions to synthesize the existing literature. They are:

- a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),***
- a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert et al. 2022b)), and***
- a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).***

Each of the three damage functions is separately estimated in combination with the socioeconomics, climate, and discounting modules. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods. GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE and DSCIM are not included in Howard and Sterner's (2017) final sample of studies. In Section 4.1 of the draft report, EPA combines the multiple lines of evidence on damages by averaging the results across the three damage module specifications to present SC-GHG estimates for a given range of discount rates.

- a. *Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

I suggest EPA considering dropping the use of the term “sector” to describe components of damage and instead use their alternative term “impact category.” The term, “sector” in economics typically refers to an industry (agriculture, manufacturing, etc.) which is not what is being referenced here. Further, the broad terms of health, agriculture, suggest that the EPA has monetized and considered all impacts in that category, but in most/all cases, many impacts are currently omitted. For example, DSCIM incorporates only mortality under the “health sector.” The agricultural sector, etc. are also only partial.

Footnote 76 documents the source of the value of risk reduction (VSL) as being the dated 1990 estimate, updated for income growth. Numerous authors have called for these numbers to be updated for years. Their continued use may be understandably pragmatic for now but updating these numbers using improved methodology and data is long past due. I urge EPA to prioritize that effort.

It is unclear how summing 5 separate damage estimates relates to the underlying welfare theory. Specifically, each of the 5 damage estimates constructs a separate welfare measure that come from different revealed preference methods. In the case of mortality valuation, the use of a value of risk reduction construct to multiply by the expected change in mortality is theoretically consistent with the ex-ante welfare values that are appropriate. I am less clear how the energy component--- the change in energy expenditures --- is related to the ex-ante wtp to avoid uncomfortable temperatures. Since estimates of increased energy use to heat and run air conditioning is approach, it seems that the theoretical basis should come from the use of the revealed preference methods of defensive expenditure. In that case the literature on how to use defensive expenditures to estimate the bounds on theoretically correct wtp is necessary to make this linkage. Bartik developed a key result (also covered nicely in coverage in applied welfare economics textbooks (Bockstael and McConnell, Phaneuf and Requate, Freeman et al.)) that make clear these expenditures can only be viewed as lower bounds. Given that the estimates in this report indicate a negative estimate for energy costs, and that number is nothing but a lower bound, that's a point that is important to make. I think similar questions can be asked about the other issues. This question is probably best thought of as a long run component of a research agenda rather

than something necessary to address now.

The presentation of the damage module from GIVE suffers from some of the shortcomings of the presentation of DSCIM. There is reference to unrefereed materials to justify approaches here.

Better explanation of the welfare theory connection would be useful. And any reliance on gray literature/non-refereed would benefit from either a more detailed technical appendix or perhaps more explanation here.

Finally, NASEM suggested including estimates of physical changes as well as monetized values. A set of figures or tables to present those comparisons over time could be very enlightening.

- b. Does the draft report's use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes to you recommend? Do you think that there is a better approach for this update?***

See above.

- c. For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.***

See above.

- d. Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.***

See above.

- e. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?***

See above.

- f. Do you have longer-term recommendations for improvements to this module in future updates?***

The last few paragraphs of section 3.2 suggest seemingly straightforward ways to include additional damage values into the SCC estimates, why not do them?

5. *Discounting module*

The discounting module used in the draft report relies on a set of calibrated dynamic discount rates. These rates were developed using a Ramsey discounting approach that endogenously connects the discount rate and socioeconomic scenarios where the Ramsey formula parameters are empirically calibrated to match near-term consumption interest rates and reconcile long-run interest rate behavior and economic growth uncertainty consistent with the RFF-SPs. Uncertainty in the starting rate is addressed by using three near-term target rates – 1.5, 2.0, and 2.5% - based on multiple lines of evidence on observed interest rate data.

- a. *Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?*

This area is better addressed by other reviewers.

- b. *Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.*

This area is better addressed by other reviewers.

- c. *Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.*

This area is better addressed by other reviewers.

- d. *Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?*

This area is better addressed by other reviewers.

- e. *Do you have longer term recommendations for improvements to this module in future updates?*

This area is better addressed by other reviewers.

6. *Other*

- a. *Accounting for risk aversion:*

- i. *Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than*

the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?

Yes, this is a much-improved approach

ii. Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.

No.

iii. Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?

My primary suggestion for this section is to provide more information and tables comparing the results. Table 3.1.1 – 3.1.3 report the SC-GHGs by sector by damage module, but not by “sector”. To better compare and understand differences and similarity in the 3 damage modules, it would be very useful to see these disaggregated by sector and by region of the world. Table 3.1.4 does provide a comparison across sectors by only for a single year, not its time path over time and not by geography region.

The welfare gain predicted for the DSCIM energy estimates reported in Table 3.1.4 needs explanation. My suspicion is that this reflects the lower bound nature of an expenditure change relative to the underlying welfare measure being sought to estimate (see Bartik bounds and related work).

I encourage EPA to provide physical effects of whatever damage categories they can that are not monetized even if monetization is a ways off. This is consistent with best practices as articulated in EPA's Guidance for Economic Analysis and was recommended by the NASEM report. I also feel that it would add transparency.

iv. Do you have longer run recommendations for improved ways to account for risk aversion in future updates?

No.

b. Characterization of distributional impacts and other presentational recommendations for the draft report:

i. Given the spatial resolution available in the modeling performed for this update,

do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?

Presenting physical impacts by region as well as monetized impacts might help provide a more thorough understanding of the distributional effects.

ii. Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?

The explanation provided for using global damages vis-à-vis the effect of not doing so for US citizens is well stated. From the perspective of a worldwide social planner, there is of course another important reason for urging a global number. If each country were to design policy to equate marginal damages with marginal abatement costs using only the damages their pollution inflicts on their own citizens, the world would not achieve the socially optimal level of emissions as many damages would be omitted.

iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?

No.

c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?

No.

III. SPECIFIC OBSERVATIONS

Page	Paragraph	Comments or Questions
5		the “fourth” value should be “third”
18		clarify that the report uses “income” as equivalent to “GDP”

Michael Oppenheimer, PhD

Peer Review Comments on the TSD: Social Cost of Greenhouse Gas

Michael Oppenheimer, PhD

I. GENERAL IMPRESSIONS

The document **Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances** is, as far as this reader can discern, accurate in its representation of the current literature. The presentation is exceptionally clear and would be accessible to a knowledgeable non-expert working in the climate policy domain. The document's conclusions are sound *within the self-constrained scope of its analysis*. However, the document does not go as far as it could in exploring the implications of ambiguities, sensitivities, and other characterizations of uncertainty. In the long history of the climate change problem, it is this very arena, almost by definition, that has continued to provide surprising results and outcomes that force policy makers to update their approaches. For example, while the report does a good job of accounting for a range of plausible outcomes for ice sheet loss, it treats coastal adaptation “based on an optimistic assumption that optimal, lowest cost adaptation opportunities will be realized globally under perfect foresight about SLR”. While the report does label this assumption as “optimistic”, it begs the question of why a pessimistic assumption wasn't likewise deployed. In other cases, “many interactions and feedback effects are not yet represented, both in modeling physical earth system changes [e.g., feedback effects of tipping elements] and economic damages.” Even though only one view of coastal adaptation and therefore only one end of a large range of possibilities is deployed for coastal damages, this may be better than the report's other shortcoming: presenting no estimate at all for other features of the physical or social systems. Simply put, the number of “Not Yet Incorporated” features in Table 3.2.1 is rather startling. Certainly, an approach more sophisticated than the 25% cost increment embedded in some of the modeling referred to but not deployed here could have been introduced, at least for some sectors/features of the system. The rationale that the current approach allows the report to claim it uses “the most conservative damage function specification” will undoubtedly be challenged because some of the omitted features might, in fact, reduce damages, if (in my judgment) modestly. Worse yet, “most conservative” is not very useful as a guide to policy if no quantification or qualitative expert judgment, even of low confidence, is attempted for such a large part of the scope of the problem. Authors of this report may have been constrained by the limitation of consistency with the temperature-only estimates provided by the Climate Impact Lab, thus restricting the analysis to impacts that are easily represented as functions of temperature. However, this approach could and should have been supplemented with additional modeling (e.g., semi-empirical, RCM's) or estimation procedures (meta-analysis of existing literature, sensitivity testing) that would have permitted bounding of costs of other impacts.

II. RESPONSE TO CHARGE QUESTIONS

1. *Use of a modular approach to the methodological updates*

Consistent with the National Academies' near-term recommendations, EPA separately updates the methodology in each step of the SC-GHG estimation—socioeconomic and emissions projections, climate science, economic damages, and discounting— increasing transparency and ease of updating each component to reflect the latest expertise from the

scientific disciplines relevant to that component. Using this modular approach, EPA updated each step in SC-GHG estimation to improve consistency with the current state of scientific knowledge, enhance transparency, and allow for a more explicit representation of uncertainty.

- a. Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?**

The modular approach is certainly a major improvement over the previous approach because it increases transparency, avoids or makes more transparent many of the implicit and explicit expert judgments that the modeling underlying the previous approach obscured, and makes far easier the inclusion in the report of results from empirical modeling. The latter has in many ways revolutionized the study of many climate impacts as represented by a large and rapidly increasing literature. To not be able to include these results in a consistent manner would have undermined the credibility of this report.

- b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?**

Yes, very clearly, and I have no specific recommendations with regard to the presentation. As indicated in my response to Question 1, I do have specific and general criticisms of the substantive approach, particularly regarding the treatment of uncertainty.

- c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.**

As noted above, the treatment of uncertainty is incomplete and could be improved. In particular, where physical science or adaptation science is incomplete, a one-ended (fuzzy) bounding exercise, as used for adaptation to coastal impacts, will not do. There is really no excuse for not using available information to estimate some version of a low-probably “upper bound,” especially when high impact phenomena are at issue (like damage from intense precipitation events). This is old ground that has been covered and contested over and over and I find it surprising that this report retreated to what the authors probably considered to be safe ground, the so-called “conservative damage function specification.” In fact, this report is inconsistent in using the range determined by deploying both FACT and BRICK for sea level rise while not using a similar approach for other features, which instead were simply elided. Had this lacuna been thought about in advance, a bounding exercise for features other than sea level rise but analogous to the treatment in IPCC Sixth Assessment Report, WGI, Chapter 9.6.3.2 could have been developed in a timely fashion. At this time, it may or may not be too late to revise the approach to uncertainty, but this ought to be a top priority for the next cycle of SCC estimation. An adequate representation of the right-hand tail is a critical feature for policy makers and aside from the bounds on outcomes implied by using both FACT and

BRICK, this report fails to estimate tail risk, e.g., consequences of tipping points and other high-impact, low likelihood phenomena.

- d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?*

See my answer to (c).

2. Socioeconomic and emissions module

The socioeconomic and emissions module used in the draft report relies on a new set of socioeconomic and emissions projections developed under the Resources for the Future Social Cost of Carbon Initiative (collectively referred to as the RFF-SPs) (Rennert et al. 2022a). The RFF-SPs are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO₂, CH₄, and N₂O) to 2300 that were generated using statistical and structured expert judgement methods and accounting for future policies and interdependencies. The country-level population projections extend the fully probabilistic statistical approach used by the United Nations for official population forecasts, while incorporating improvements recommended by a panel of expert demographers (Raftery and Ševčíková 2021). The country-level empirical economic growth projections (Müller, Stock, Watson 2020) were extended in time using expert elicitation (Rennert et al. 2022a). The emissions projections are conditioned on future economic growth and a reflection of an “Evolving Policies” case (Rennert et al. 2022a).

- a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?*

I'll pass on responding here as others involved in this review have greater expertise on this particular subject.

- b. Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages of these approaches.*

See response to part (a).

- c. Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?*

See response to part (a).

- d. Do you have longer-term recommendations for improvements to this module in future*

updates?

See response to part (a).

3. *Climate module*

EPA's goal for this update of the climate module was to adopt a widely used, transparent climate model that could reflect the latest scientific understanding of the relationships between CO₂ emissions, atmospheric CO₂ concentrations, and global mean surface temperature change (and any other climatic variables required as inputs to the damage module) over time while accounting for non-CO₂ forcing and allowing for the evaluation of uncertainty. The climate module used in the draft report relies on the open source and widely used Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature change. The estimates presented in the report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b), in which the uncertain parameters have been calibrated to be consistent with the most recent assessment of the IPCC, such as the IPCC AR6 assessed likely range of 2.5 to 4°C for the equilibrium climate sensitivity.

- a. Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?*

While the climate module approach improves upon the previous framework, it falls short in producing only changes in temperature as the primary output (the motivation for which I note in General Impressions). This may be the primary reason that Table 3.2.1 has so many open circles. Much as I recommend above that the treatment of uncertainty across many features of this analysis should be broadened, I likewise recommend that some additional features of the climate system, especially precipitation, be included in SCC uncertainty range. While parameterization of global mean precipitation change as a function of temperature is often done, regional precipitation changes, which are what count for impacts, are not so easily estimated in this manner. Still, it might have been feasible to estimate an uncertainty range for regional precipitation changes. The strict adherence to FaIR's output temperatures as the sole independent variable driving impacts seems to have inhibited creativity on this score. While it may be too late now to correct this problem, it surely should be atop the agenda for the next round of SCC estimation.

- b. Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.*

The following might be feasible: a limited number of simulations with a few ESMs (or

several realizations of one ESM) that have shown some skill with regional precipitation could be run in order to develop upper and lower limits on regional precipitation change.

- c. Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.*

Given current ice sheet modeling limitations, the key consideration with regard to the physical science aspects is whether the approach used in this report provides uncertainty bounds that are consistent with AR6. Since this is the case, I have no additional recommendations on the approach to modeling physical sea level rise. However, assuming your request's use of "impacts" in this question includes the ameliorating (or worsening) effects of adaption (maladaptation), see my comments under General Impressions on the inference of damages from the estimated range of rise. The assumption of optimal adaptation is absurd on its face given all evidence to the contrary for the US in particular. See a summary of my presentation to PCAST, October 18, 2021 at

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjripOu68z9AhUgFVkfFHQzDD3wQFnoECAgQAQ&url=https%3A%2F%2Fwww.whitehouse.gov%2Fwp-content%2Fuploads%2F2021%2F12%2FMinutes_PCAST_Oct-18-19-2021_FINAL.pdf&usg=AOvVaw2V072hEMrr5EgbzvFxjekk

Notably, Federal policy toward adaptation has improved since then but the institutional obstacles noted largely remain unaddressed.

- d. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?*

See my previous comments.

- e. Do you have longer-term recommendations for improvements to this module in future updates?*

A start has been made by several research groups around the world on realistic modeling of coastal adaptation. EPA ought to do better in the future than merely asserting "lower bound" to justify using a ridiculously optimistic assumption for coastal adaptation. Let's try to get a plausible upper bound, too.

4. Damages module

Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. EPA's goal for this module is to evaluate the large increase in research on climate impacts and damages in the time since the models underlying the IWG methodology to date were published. The damages module in this draft report relies on three damage functions to synthesize the existing

literature. They are:

- *a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),*
- *a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert et al. 2022b)), and*
- *a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).*

Each of the three damage functions is separately estimated in combination with the socioeconomics, climate, and discounting modules. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods. GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE and DSCIM are not included in Howard and Sterner's (2017) final sample of studies. In Section 4.1 of the draft report, EPA combines the multiple lines of evidence on damages by averaging the results across the three damage module specifications to present SC-GHG estimates for a given range of discount rates.

- a. Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

Yes, see my comments in response to General Impressions and Question II.1.a. The inclusion of empirical modeling as an equal contributor to this assessment provides an important improvement. Of course, more work needs to be done to understand the ways the processes and empirical damage functions differ from the current method versus the earlier approach, especially with regard to their respective abilities to capture the effect of adaptation, if they do at all. Furthermore, the out-of-sample question needs to be explored in great detail for particular impacts in order to assess the limitations of projection based on inference from empirical studies (see for example, the Wagner submission, Fig. 3A and related comments). This should be a project for future research.

- b. Does the draft report's use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes to you recommend? Do you think that there is a better approach for this update?*

I believe that comparing results from these three research frameworks provides as credible an assessment as is now possible within the limitations of the modeling approaches deployed within each framework. I worry much more about what was left out (see Table 3.2.1) as a source of error than I worry about the way the modeling of the included impacts was aggregated and the aggregations presented and compared. However, my concerns about the treatment of uncertainty and adaptation noted above remain.

- c. *For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.*

I am not as expert on current valuation methods as others reviewing this report so I will refrain from commenting on this one.

- d. *Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.*

See my foregoing comments on precipitation and sea level rise adaptation.

- e. *Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?*

No.

- f. *Do you have longer-term recommendations for improvements to this module in future updates?*

See above – the presentation is fine; the issue is the missing content.

5. *Discounting module*

The discounting module used in the draft report relies on a set of calibrated dynamic discount rates. These rates were developed using a Ramsey discounting approach that endogenously connects the discount rate and socioeconomic scenarios where the Ramsey formula parameters are empirically calibrated to match near-term consumption interest rates and reconcile long-run interest rate behavior and economic growth uncertainty consistent with the RFF-SPs. Uncertainty in the starting rate is addressed by using three near-term target rates – 1.5, 2.0, and 2.5% - based on multiple lines of evidence on observed interest rate data.

- a. *Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?*

Better for others to handle this one.

- b. *Are there discounting approaches other than Ramsey discounting that the EPA should*

consider for this update? Please describe the advantages of these approaches.

Same as (a).

- c. Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.*

Same as (a).

- d. Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?*

Same as (a).

- e. Do you have longer term recommendations for improvements to this module in future updates?*

Same as (a).

6. Other

- a. Accounting for risk aversion:*

- i. Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?*

Better for others to handle this.

- ii. Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.*

Better for others to handle this.

- iii. Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?*

Better for others to handle this.

- iv. Do you have longer run recommendations for improved ways to account for risk aversion in future updates?*

Better for others to handle this.

- b. Characterization of distributional impacts and other presentational recommendations for the draft report:*

- i. Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?*

Given the high spatial resolution of the impact models, it seems a pity that ways could not be found to estimate distributional impacts beyond the mostly descriptive statements in the report. The next generation of SCC assessments should make it a priority to determine which constraints are limiting and develop estimation procedures to overcome these limitations. Once again, taking an approach that emphasizes plausible upper and lower bounds on distributional consequences could provide useful information for policy makers even before end-to-end high-resolution modeling is available, even if not totally consistent with the aspiration for the sort of quantitative distributions derived in this report.

- ii. Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?*

Damages to the US are discussed in several specific contexts, for instance, sectors not included in this report's SCC results because a basis for producing global numbers is lacking. However, no overall comparison of US-only and global values is highlighted – if it's there the reader must search hard to find it. This may have been seen as appropriate following the guidance to derive values of SCC encompassing global damages. Nevertheless, US-only numbers would be interesting material for the report to highlight and discuss.

- iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?*

No.

- c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future*

updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?

See subparts.

III. SPECIFIC OBSERVATIONS

No comments provided.

Wolfram Schlenker, PhD

Peer Review Comments on the TSD: Social Cost of Greenhouse Gas

Wolfram Schlenker, PhD

I. GENERAL IMPRESSIONS

EPA’s “Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances” outlines a revised methodology to derive the social cost of greenhouse gases. I believe the report is well written: it provides a history of how the social cost of carbon was previously derived, a rationale for its revision, specifically how EPA is following the guidelines given by the National Academies of Sciences, Engineering, and Medicine (NASEM), as well as planned further revisions. I very much support the modular framework NASEM recommended, as it makes the individual steps in how the Social Cost of Greenhouse Gases (SC-GHG) is derived clear and allows people to modify individual components when new data becomes available or to test the sensitivity of the results to various parameters. Moreover, the analysis went away from the highly aggregated Integrated Assessment Models (IAM) that had previously been used and that did not incorporate the latest empirical findings.

It should be noted that several comments were very complimentary for the work EPA had conducted.⁵ I concur – EPA is advancing our state of knowledge. There are specific suggestions for improvements I will discuss in more detail below, but I believe the proposed rule is an important step forward.

There are some comments whether the derived estimates are defensible.⁶ I do not share those concerns. While EPA acknowledges that there are uncertainties, simply not using any value because the analysis is uncertain does not avoid the problem but instead chooses a value of zero. Given the presented evidence, EPA’s revised values are clearly more defensible than a value of zero. A lot of evidence is given in the cited studies that changing weather patterns have an effect on societies.

II. RESPONSE TO CHARGE QUESTIONS

1. *Use of a modular approach to the methodological updates*

Consistent with the National Academies’ near-term recommendations, EPA separately updates the methodology in each step of the SC-GHG estimation—socioeconomic and emissions projections, climate science, economic damages, and discounting— increasing transparency and ease of updating each component to reflect the latest expertise from the scientific disciplines relevant to that component. Using this modular approach, EPA updated each step in SC-GHG estimation to improve consistency with the current state of scientific knowledge, enhance transparency, and allow for a more explicit representation of uncertainty.

⁵Comment 2433: “[...] the Joint Environmental Commenters strongly support EPA’s supplemental proposal for new and existing sources [...]” Comment 2410 “[...] we strongly support EPA’s Supplemental Proposal.”

⁶Comment 2339: “The SC-GHG estimates are highly speculative, policy-laden, and ultimately non-scientific.”

Comment 2359: “Undetectable, non-experiential effects are ‘benefits’ in name only. Illusory benefits should not be weighed [...]”

- a. Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?**

The derivation of the SC-GHG has always required the four steps (modules) identified in Figure 2.1, however, earlier studies have often used simplifying assumptions on various parameters, e.g., picking an exogenous GDP or population growth rate, or implicit performed the three steps without breaking them apart. The modular approach has three major advantages: first, it clarifies the underlying assumptions and uncertainties of each step by dedicating a separate section to it. Second, it allows for easy updating and revisions as new data become available – only the corresponding module will have to be adjusted. Finally, the sensitivity of the results to various modules is easily derived, e.g., several comments were with regard to the appropriate discount rate.

- b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?**

The modular approach is well described.

- c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.**

NASEM had short-term and long-term recommendations. I believe EPA has followed the recommendations it was given for short-term revisions. There are of course additional steps that can be done, as the report acknowledges, but EPA has done a remarkable step forward.

- d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?**

There is one potential downside to the modular approach: breaking the analysis into four subgroups might make feedback loops (shown in Figure 2.1) more challenging to implement as each module is developed in isolation and builds on a previous module. EPA acknowledges in Figure 2.3.1 that currently feedback loops are not included. The large uncertainty on future emissions paths is in part due to these feedback loops. The current approach is very much linear going from module 1 to module 4, but I would encourage EPA to incorporate feedback loops going forward, e.g., how is GDP growth impacted by climate change itself? Will warming induce additional demand for cooling (ACs) that itself causes more emissions and amplify warming?

2. Socioeconomic and emissions module

The socioeconomic and emissions module used in the draft report relies on a new set of socioeconomic and emissions projections developed under the Resources for the Future Social Cost of Carbon Initiative (collectively referred to as the RFF-SPs) (Rennert et al.

2022a). The RFF-SPs are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO₂, CH₄, and N₂O) to 2300 that were generated using statistical and structured expert judgement methods and accounting for future policies and interdependencies. The country-level population projections extend the fully probabilistic statistical approach used by the United Nations for official population forecasts, while incorporating improvements recommended by a panel of expert demographers (Raftery and Ševčíková 2021). The country-level empirical economic growth projections (Müller, Stock, Watson 2020) were extended in time using expert elicitation (Rennert et al. 2022a). The emissions projections are conditioned on future economic growth and a reflection of an “Evolving Policies” case (Rennert et al. 2022a).

- a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?*

The report makes the underlying assumptions clear. There is a lot of uncertainty about future development, e.g., the confidence band on population forecasts by 2030 is very large. EPA does its best to incorporate this uncertainty in its analysis by following the statistical interpolation paired with expert solicitation that NCSEM recommended.

- b. Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages of these approaches.*

None in the short-term. I would encourage them to take feedback loops seriously for the long-term revisions (GDP growth is itself a function of climate change).

- c. Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?*

The one comment I have on clarity is to better explain that the uncertainty bands include policy options. When people see the wide confidence bands by 2300, an intuitive response might be to discredit the model as unreliable given the large range of possible outcomes. However, a big fraction of the “uncertainty” is due to policy choices, which aren’t modeling uncertainty – see next point. Treating each RFF-SP as equally likely might make it look as these are random possible outcomes of the future – but again, they are in large part choices.

- d. Do you have longer-term recommendations for improvements to this module in future updates?*

The report states “RFF-SPs explicitly account for the likelihood of future climate policies,” so part of the divergence in the observed emission pathways is hence due to

public policy choices. I would separate the range of future emissions that is (i) due to modeling uncertainty, e.g., on population growth, from (ii) emissions changes that are due to climate policies. That makes it clearer what fraction we don't know (modeling uncertainty) versus what are simple choices.

3. *Climate module*

EPA's goal for this update of the climate module was to adopt a widely used, transparent climate model that could reflect the latest scientific understanding of the relationships between CO₂ emissions, atmospheric CO₂ concentrations, and global mean surface temperature change (and any other climatic variables required as inputs to the damage module) over time while accounting for non-CO₂ forcing and allowing for the evaluation of uncertainty. The climate module used in the draft report relies on the open source and widely used Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature change. The estimates presented in the report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b), in which the uncertain parameters have been calibrated to be consistent with the most recent assessment of the IPCC, such as the IPCC AR6 assessed likely range of 2.5 to 4°C for the equilibrium climate sensitivity.

- a. *Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?*

This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers.

- b. *Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.*

This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers.

- c. *Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.*

This is outside my area of expertise and I defer to my colleagues on the committee that are climate modelers.

- d. *Do you have recommendations for strengthening the presentation of this module, e.g.,*

with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?

The report states how “Reduced-complexity climate models [...] are computational emulators of the climate system.” Predicted climate change is highly non-uniform, with higher latitudes seeing more warming. The emulator capture this, but the report exclusively focuses on the mean temperature increase. I would highlight more that these mean increases translate into non-uniform warming around the globe, with the US seeing above-average warming. This non-linear warming is then used in the next section on damages.

e. Do you have longer-term recommendations for improvements to this module in future updates?

This outside my area of expertise and I defer to my colleagues on the committee that are climate modelers.

4. Damages module

Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. EPA’s goal for this module is to evaluate the large increase in research on climate impacts and damages in the time since the models underlying the IWG methodology to date were published. The damages module in this draft report relies on three damage functions to synthesize the existing literature. They are:

- *a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),*
- *a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF’s Social Cost of Carbon Initiative (Rennert et al. 2022b)), and*
- *a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).*

Each of the three damage functions is separately estimated in combination with the socioeconomics, climate, and discounting modules. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods. GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE and DSCIM are not included in Howard and Sterner’s (2017) final sample of studies. In Section 4.1 of the draft report, EPA combines the multiple lines of evidence on damages by averaging the results across the three damage module specifications to present SC-GHG estimates for a given range of discount rates.

a. Does the damages module in this draft report offer a more robust representation of the

current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?

The NASEM highlighted that the previous IAMs did not incorporate the latest scientific findings. The current analysis is a big step forward. I congratulate the EPA for its efforts to include three separate well-described approaches. These include both micro-level statistical studies as well as aggregate damage functions and a meta-analysis. I realize that meta-studies are common in the literature, but I am personally a bit hesitant to employ them as they place equal weight on each study when I believe some are more defensible than others. As discussed below, the sectoral damages vary vastly by approach and it would be interesting to dive further into where the differences stem from going forward and go with the number that is most defensible and describe the others as sensitivity checks.

- b. Does the draft report's use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes to you recommend? Do you think that there is a better approach for this update?***

I think the EPA has made a big step forward by switching to the modular approach and including three different damage approaches. The one exception is comment 2183, who talk about possible tipping points and encourage EPA to highlight them further. While I wouldn't ask EPA to include them in their baseline numbers, it would be informative to include them in a sensitivity check to showcase how much they might change the results. One of the largest concerns for me about the current approach is that the approach might not correctly capture that we are setting irreversible self-enforcing feedback loops into motion and hence underestimate future damages.

As was discussed in our meeting, it would be great to stress that additional sectoral impacts will be added in the future. They might also result in benefits for some sector (e.g., recreation).

- c. For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.***

The biggest sectoral impact is health (Table 3.1.4), which crucially depends on the value of a statistical life (VSL). There is an inherent tension between the current report and how EPA traditionally uses VSL. It is my understanding that EPA uses the same VSL for all ages (it once discussed using different values by age but then reverted back giving ethical considerations), even though there are revealed preference studies showing that it varies by age. Carleton et al. (2022) does use age-years lost, implying a different VSL per age group (older people have fewer life years left). Moreover, Carleton et al. (2022) uses an income-elasticity of one, which implies that if a person dies in a country that has one tenth of US income, it is valued at one tenth the US value. Scaling VSL by income has a

theoretical and empirical underpinning: people who are faced with tradeoffs that can lower their mortality risk reveal a lower willingness to pay when their income is lower.

However, as comment 2464 points out, this is very different from the setting of greenhouse gas emissions where most of the emissions are caused by high-income developed countries, while most damages are felt in low-income countries (Figure 9 in Carleton et al). There is evidence that people care about the distributional aspects, e.g., Cai, Cameron, and Gerdes (2010) <https://doi.org/10.1007/s10640-010-9348-7>

I respectfully disagree with the comments made by Professor Kling. Again, there is a big difference whether people themselves make choices / tradeoffs between increased mortality risks and or whether it is imposed by others. There can be a big difference between willingness to pay and willingness to accept, see Hanemann (1991): <https://www.jstor.org/stable/2006525>. In his proposition 2, he shows that if there is zero substitutivity, the former could be finite while the latter is infinite. So the VSL for action caused by others might be much higher. I am not aware of VSL studies in developing countries that look at harm (mortality risk) that is not endogenous to the country but caused by authors.

There is also an ethical perspective. The same studies, e.g., Viscusi and Masterman <https://doi.org/10.1017/bca.2017.12>, that argue for an income elasticity of 1 for international setting, say it should be 0.5-0.7 for domestic setting. Yet, EPA does not differentiate VSLs by income within the US (New York has more than twice the average income than Mississippi, and we don't value deaths in Mississippi less than New York).

Let me illustrate the flip-side of this argument: the report outlined why using global impacts is appropriate, partly because we expect other countries to join in using similar regulation. It might be hard for the equivalent of EPA in India to argue to its citizens that a death in the US is 32 (current ratio of GDP per capita) as bad as a death in India.

What would be sensitivity of the SC-GHG to using different income-elasticities for the global VSL – I believe this should be discussed, at least in an appendix.

- d. Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.***

EPA has based their analysis on three highly respected analyses (published in *Nature* and the *Quarterly Journal of Economics*) and incorporated the sectors used in those studies. I don't think it is realistic for EPA to add additional sectors that were not covered in the original studies. However, it might be good to note already now that future revisions will include additional sectors, however, I do believe that mortality will likely continue to be the most significant part (there is a reason studies focus on this sector first).

- e. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or***

characterization of uncertainty in the draft report?

Since they are based on published studies, interested readers can revert to those studies. A few recommendations I have are:

- 1) Further outline the differences between studies for various sectors in Table 3.1.4.
- 2) Figure 2.3.2 plots the damage function.
 - a) Please plot them all using the same y-scale so they are comparable.
 - b) The one for the GIVE model seems to be consistently higher damages for various temperatures - I realize this is for damages in 2100 (one point in time)
 - +1C: GIVE 1%, DSCIM: 0%
 - +2C: GIVE 2.5%, DSCIM: 0%
 - +3C: GIVE 4%, DSCIM: 1%
 - +4C: GIVE 5%, DSCIM: 2%
 - +5C: GIVE 7.5%, DSCIM: 4%
 - +6C: GIVE 10%, DSCIM: 6.5%

Yet, the social cost of carbon is higher for DCSIM than GIVE. What is the intuition for this? Is it in the time profile (i.e., Figure 2.3.2 gives damages in 2100, where GIVE is higher, but DSCIM has higher damages by say mid-century?). But then, DSCIM gives lower SC-GHG for methane, which has a faster impact on warming and I would have expected the S-CH₄ methane to be even bigger under DSCIM model). Could you give some intuition how they compare over time.

f. Do you have longer-term recommendations for improvements to this module in future updates?

EPA already outlined how they want to include other sectors, including non-market impacts. One important point to keep in mind when adding sectors and constructing confidence bands is that errors across sectoral impacts are likely highly correlated and not independent.

I believe there are especially two areas that warrant further study in the future that could significantly alter the overall results. First, one of the biggest unknowns is adaptation and whether it can significantly lower the predicted cost. The Carleton et al 2022 paper estimates adaptation based on revealed preferences of who has adapted so far in warmer climates, but are they representative? Full disclosure: it uses the same approach to adaptation that I have used before for crops - so the same criticism applies to my studies. Specifically, areas that are currently warmer have lower crop yields (and lower GDP), so the benefits from innovation are currently lower than what they would be if currently moderate climates (with higher yields or GDP) become warmer. The incentives for innovation might hence be higher in the future as what is picked up in the current data. Moreover, the analysis omits that we might have new technologies available in the future that weren't available in the past. Taken together, we might underestimate adaptation possibilities and hence overestimate damages.

The second point relates to migration. In my opinion, one of the most disruptive effects of climate change might be the need to relocate – locally from flood-prone areas or even long-distance as regions become uninhabitable.

5. Discounting module

The discounting module used in the draft report relies on a set of calibrated dynamic discount rates. These rates were developed using a Ramsey discounting approach that endogenously connects the discount rate and socioeconomic scenarios where the Ramsey formula parameters are empirically calibrated to match near-term consumption interest rates and reconcile long-run interest rate behavior and economic growth uncertainty consistent with the RFF-SPs. Uncertainty in the starting rate is addressed by using three near-term target rates – 1.5, 2.0, and 2.5% - based on multiple lines of evidence on observed interest rate data.

- a. Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?*

The update module provides a theoretical underpinning for why the chosen interest rates are used that are in line with the recommendation of NASEM. While some comments (e.g., 2253) have argued that an interest of zero is appropriate, I do not find this convincing. The Ramsey formula is a composite of a pure time preference (which one might argue should be set to zero) and a second term that incorporates that future generation are better off (wealthier) than the current generation. Taking money from the (poorer) present and consuming it in the (wealthier) future, when the value of having an extra dollar is lower, leads to a welfare decline. Within this framework, the only reason that we discount with the second term is because the future is better off. If climate change were so catastrophic that the future is worse off than the present, the interest rate would actually be negative. This might be worth highlighting.

- b. Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.*

I believe the Ramsey formula is appropriate.

- c. Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.*

No comment.

- d. Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?*

See part a. Maybe describe why the interest rate is positive in more detail and under what conditions it would be negative.

- e. Do you have longer term recommendations for improvements to this module in future updates?*

No comment.

6. Other

- a. Accounting for risk aversion:*

- i. Does the methodology in the draft report more explicitly reflect existing evidence on individuals' preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?*

Comment 2183 had some useful suggestions on going from a positive to normative justification for the chosen interest rate – this would be worth considering when providing justification, as well discussion on the climate beta. The comment is a better summary than what I can provide.

- ii. Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.*

No comment.

- iii. Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?*

No comment.

- iv. Do you have longer run recommendations for improved ways to account for risk aversion in future updates?*

No comment.

- b. Characterization of distributional impacts and other presentational recommendations for the draft report:*

- i. Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?*

Several of the critical comments highlighted the cost imposed on local natural gas producers. It is standard practice for studies using the Kaldor-Hicks criterion to weight losses against gains, without actually making transfer payments. However, as Arrow et al (1996) (<https://doi.org/10.1126/science.272.5259.221>) point out, “Although benefit-cost analysis should focus primarily on the overall relation between benefits and costs, a good analysis will also identify important distributional consequences.” While the overall benefits clearly swamp the cost, does EPA have ideas or recommendations on how the most negatively impacted communities can be helped.

- ii. Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?*

The report is clear in why it uses global numbers. I support the approach taken. In a global public goods setting, the solution to the problem where every country only focuses on their domestic benefits. Cost will be suboptimal. Comment 2281 provides further arguments for why this is appropriate – I am not a legal scholar so defer to those arguments.

- iii. Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?*

I feel it is clearly written and makes adjustments in response to the recommendation by NASEM. The only recommendation I have is the discussion around Table 3.1.4. It would be informative to get further insights for why the analyses are so different for some sectors, especially agriculture, the sector where DSCIM and GIVE diverge the most.

- c. Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?*

Let me restate some of the longer-term issues that are outstanding, some of which I discussed before:

- 1) Include additional sectors (including migration), as well as correlation between sectoral damage estimates
- 2) Several studies suggest that extreme temperatures and precipitation events cause especially large damages, so incorporate climate extremes and how they evolve.
- 3) Include feedbacks between damage module and socio-economic module, model price effects.
- 4) Innovation and adaptation potential – do we correctly capture what will be available going forward. It is an active research area, and I would encourage EPA to incorporate new findings as they become available.

III. SPECIFIC OBSERVATIONS

Page	Paragraph	Comments or Questions
51	Figure 2.3.2	I think comparison across the three models would be easier if each of the three plots use the same 0-20% scale for the y-axis.

Gernot Wagner, PhD

Peer Review Comments on the TSD: Social Cost of Greenhouse Gas

Gernot Wagner, PhD

I. GENERAL IMPRESSIONS

The *Technical Support Document: Social Cost of Greenhouse Gas Estimates* represents a real step change in the formal calculation of the U.S. Social Cost of Carbon (SC-CO₂), not least because of its explicit calculation of the Social Cost of Methane (SC-CH₄) and Nitrous Oxide (SC-N₂O). It is generally well-written, technically sound, responsive to a host of comments and inputs (e.g. National Academy of Sciences 2017; Carleton and Greenstone 2021; Wagner et al. 2021) since the prior updates under the Obama administration (U.S. Government Interagency Working Group on Social Cost of Carbon 2015), and generally represents well the emerging consensus in the literature (e.g. Moore et al. 2023).

The ~\$200 ‘headline’ number (for a 2% discount rate) for each ton of CO₂ emitted today is well within the emerging scientific consensus of a significant body of work that shows climate change is indeed much more costly than the prior ‘interim’ ~\$50 number would suggest (e.g. Rennert et al. 2022; Moore et al. 2023; Bauer, Proistosescu, and Wagner 2023).⁷

The 2% discount rate, too, is appropriately chosen to replace what the U.S. Government Interagency Working Group’s (2015) effort called the “central” 3% rate, with significant work pointing to using the lower 2% rate instead (e.g. Drupp et al. 2018; Council of Economic Advisors 2017; Greenstone and Stock 2021; Wagner et al. 2021). In fact, the proposed update to Circular A-4 argues convincingly for an even lower discount rate of 1.7% to be used in the short term (U.S. Office of Management and Budget (OMB) 2023).

My one major recommendation is to improve the representation of climatic and climate-economic risks and uncertainties in the report, perhaps especially in the Executive Summary and the main Table ES.1 (see more below) but also throughout the report. The resulting SCC presented here can only be described as a ‘partial’ estimate, with a potentially long upper tail. That fact needs to be clear and consistently presented throughout the report.

II. RESPONSE TO CHARGE QUESTIONS

1. *Use of a modular approach to the methodological updates*

Consistent with the National Academies’ near-term recommendations, EPA separately updates the methodology in each step of the SC-GHG estimation—socioeconomic and emissions projections, climate science, economic damages, and discounting— increasing transparency and ease of updating each component to reflect the latest expertise from the scientific disciplines relevant to that component. Using this modular approach, EPA updated each step in SC-GHG estimation to improve consistency with the current state of

⁷ Amazingly, even Barrage and Nordhaus’s (2023) recent analysis agrees with this broad assessment. They do argue for an “optimal” carbon price of ~\$50/t CO₂. However, as they show in Figure 8, a discount rate of 2% would indeed come close to a \$200 SCC.

scientific knowledge, enhance transparency, and allow for a more explicit representation of uncertainty.

- a. Does the modular approach taken in this draft report offer an improved opportunity to draw on expertise from the wide range of scientific disciplines relevant to SC-GHG estimation relative to the estimation approach underlying the IWG methodology to date (which relies on the default bundled structure of the DICE, PAGE, and FUND integrated assessment models)? Why or why not?**

It does, and it does so well. The modular framework directly responds to calls from the U.S. National Academy of Sciences (2017) for just such a modular framework. The implementation builds on an impressive modeling effort spearheaded by Resources for the Future's Social Cost of Carbon Initiative, culminating in the Greenhouse Gas Impact Value Estimator (GIVE) model (Rennert et al. 2022) and the 'Mimi' modeling platform created by David Anthoff, Richard Plevin, Cora Kingdon, and Lisa Rennels: mimiframework.org.

- b. Was the modular approach described clearly in the draft report? Do you have any recommendations for improving the presentation in the draft report?**

Yes, and no. I also appreciate that the complete replication code is available via Github: github.com/USEPA/scghg.

- c. Are there alternative, superior approaches that EPA should consider using to achieve its goals for this update? Please describe the advantages of these approaches.**

There are not, and I'm saying that as the co-author of such "alternative" approaches. Daniel, Litterman, and Wagner (2018; 2019) and Bauer, Proistosescu, and Wagner (2023) present such an "alternative" approach of treating CO₂ in the atmosphere as a "risky asset" with negative payoff. That approach results in an "optimal" CO₂ price as the *output* of a benefit-cost analysis. It is no replacement for the calculation of climate damages used in the SC-CO₂, serving as an *input* into regulatory benefit-cost analyses.

The same goes even more so for any efforts aimed at scrapping benefit-cost analyses altogether (Stern and Stiglitz 2021). It is true that other countries and jurisdictions rely less on benefit-cost analyses in setting domestic climate policy, and instead have passed laws that mandate (net) decarbonization by a date certain. Such approaches are crucial in regulatory environments where such net-zero laws are enshrined in law, and where regulatory analysis focuses on minimizing costs to achieve certain targets. That is not the case in the U.S. under most circumstances, once again pointing to the importance of calculating the SC-CO₂, SC-CH₄, and SC-N₂O as a crucial input into benefit-cost analyses (Aldy et al. 2021; Wagner 2021).

- d. Do you have longer term recommendations regarding approaches the EPA should consider for future updates?**

There are indeed longer-term improvements the EPA could take, beginning with continuing to update damage functions to reflect the latest science—i.e. moving further damages from “unquantified quantifiables” into the quantified column (Proistosescu and Wagner 2020). (Table 3.1.4 shows some of the disaggregation. It also raises further question as to whether it is indeed appropriate to average across different damage modules, or whether some are better thought as being additive.)

Then there are the many climate risks that either have not or cannot be quantified. Here, EPA needs to be clear whenever such an omission has occurred. The current EPA approach does a good job accounting for risks. However, more can and should be done, beginning with quantifying major climatic tipping points. The report cites Dietz et al. (2021); it does not incorporate the resulting numbers. (See charge question 4 below.)

Further long-term improvements should look toward better representing climate damages affecting productivity and economic growth rates (e.g. Moore and Diaz 2015), explicitly factoring in “equity weights” (e.g. Anthoff and Emmerling 2018), and considering the importance of how further structural changes in risks and uncertainties affect the distribution of the SC-CO₂ (Moore et al. 2023).

1. Socioeconomic and emissions module

The socioeconomic and emissions module used in the draft report relies on a new set of socioeconomic and emissions projections developed under the Resources for the Future Social Cost of Carbon Initiative (collectively referred to as the RFF-SPs) (Rennert et al. 2022a). The RFF-SPs are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO₂, CH₄, and N₂O) to 2300 that were generated using statistical and structured expert judgement methods and accounting for future policies and interdependencies. The country-level population projections extend the fully probabilistic statistical approach used by the United Nations for official population forecasts, while incorporating improvements recommended by a panel of expert demographers (Raftery and Ševčíková 2021). The country-level empirical economic growth projections (Müller, Stock, Watson 2020) were extended in time using expert elicitation (Rennert et al. 2022a). The emissions projections are conditioned on future economic growth and a reflection of an “Evolving Policies” case (Rennert et al. 2022a).

- a. Does the socioeconomic and emissions module in this draft report offer an improved approach for reflecting uncertainty and account for future policies and dependencies between variables than the approach used in the IWG methodology to date (which relies on four business-as-usual and one 550 ppm stabilization scenario from the Stanford Energy Modeling Forum exercise, EMF-22)? Why or why not?**

Yes. It is the most comprehensive effort to date to update the socioeconomic pathways and represents an impressive undertaking, reflecting some of the latest insights around probabilistic growth projections (e.g. Christensen, Gillingham, and Nordhaus 2018).

- b. Are there additional or alternative existing sources of probabilistic socioeconomic projections that EPA should consider for this update? Please describe the advantages**

of these approaches.

n/a.

- c. Do you have recommendations for improving the clarity and accessibility of the updated socioeconomic and emissions module? Do you have recommendations for increasing transparency and strengthening the characterization of uncertainty for this module in this update?**

Same general comment here as elsewhere: It is key to do represent the nature of risks and uncertainty in a consistent fashion. One good way to doing so might be a consistent portrayal of probability density functions across different scenarios akin to Figure 2 in Rennert et al. (2022), Figure 2 in Dietz et al. (2021), and elsewhere.

- d. Do you have longer-term recommendations for improvements to this module in future updates?**

A key longer-term improvement is an explicit treatment of adaptation to current and projected future climate damages. Doing so is difficult for a number of reasons, not least in understanding which way the sign goes. E.g. does adaptation in form of human migration count as a cost of unmitigated climate change, or does it lower costs? Even where the sign is clear, quantification is anything but simple. Yet it needs to be part of a comprehensive effort to account for the full costs of unmitigated climate change.

A second such topic concerns internalizing the rapidly declining costs of carbon mitigation technologies (Gillingham and Stock 2018). These costs do not affect the EPA’s SC-CO₂ as much as calculations of the “optimal” SC-CO₂, but they do still enter via socio-economic pathways. Consistency here is key, including e.g. with forecasts by the U.S. Energy Information Administration and other efforts (Wagner et al. 2021). Moreover, these projections are rapidly changing, not least due to major U.S. government investments in clean energy via the Inflation Reduction Act, the bipartisan infrastructure law, and the CHIPS and Science Act leading to learning-by-doing on a massive scale (e.g. Arkolakis and Walsh 2023; Wagner and Friedmann 2023).

3. Climate module

EPA’s goal for this update of the climate module was to adopt a widely used, transparent climate model that could reflect the latest scientific understanding of the relationships between CO₂ emissions, atmospheric CO₂ concentrations, and global mean surface temperature change (and any other climatic variables required as inputs to the damage module) over time while accounting for non-CO₂ forcing and allowing for the evaluation of uncertainty. The climate module used in the draft report relies on the open source and widely used Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature change. The estimates presented in the report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b), in which the uncertain parameters have been calibrated to be consistent with the most recent assessment of the IPCC, such as the IPCC AR6 assessed likely range of 2.5 to

4°C for the equilibrium climate sensitivity.

- a. Does the climate module in this draft report offer an improved representation of how GHG and other forcing agent emissions translate into climatic variables that are needed by the damage module relative to the estimation approach underlying the IWG methodology to date (which relies on the default climate process in the DICE, PAGE, and FUND integrated assessment models, except for a common probability distribution for the climate sensitivity parameter)? Why or why not?*

Yes, it does. Much work has gone into assessing climate uncertainty, oft focused on climate sensitivity uncertainty (Sherwood et al. 2020). The EPA report reflects the latest consensus assessment by the IPCC in AR6.

- b. Are there additional or alternative existing climate models that can be used to reflect the latest scientific consensus on the relationships between GHG emissions, atmospheric GHG concentrations, and surface temperature change, as well as their uncertainty, and can project their profiles over time, that the EPA should consider for this update? Please describe the advantages of these approaches.*

Sherwood et al. (2020) is indirectly cited via IPCC AR6. Given the importance of that prior assessment, I would suggest citing it here directly as well.

- c. Are there other models/methods for projecting sea level impacts resulting from temperature change than those used in the draft report that the EPA should consider for this update? Please describe the advantages of these approaches.*

n/a [I defer to other peer reviewers' expertise here.]

- d. Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report? Do you have recommendations for how to enhance the discussion of earth system changes and resulting impacts that are not yet reflected in the climate module (either in Section 2.2 or 3.2)?*

Here as elsewhere, one note on representing risks and uncertainties: Tables 2.2.1 and 2.2.2 present the long right-tailed distribution for both equilibrium and transient climate sensitivity distribution. For consistency sake, it would be good to present the calibrations of the tables graphically in a way that is consistent across modules—akin to Figure 2 in Rennert et al. (2022), Figure 2 in Dietz et al. (2021), and elsewhere. Doing so would also highlight the right-skewed nature of the climate sensitivity distributions more so than a table can.

This module also makes clear how the resulting SC-CO₂ can only be described as a 'partial' estimate, given e.g. that precipitation impacts are (largely) excluded from the analysis. The report, in part, uses the term "conservative" when it means "lower bound" and/or "partial." Calling the resulting SC-CO₂ a "partial" estimate might also be important from a process perspective, establishing the fact that the calculations will

inevitably be updated going forward.

- e. *Do you have longer-term recommendations for improvements to this module in future updates?*

n/a [I defer to other peer reviewers' expertise here.]

5. Damages module

Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. EPA's goal for this module is to evaluate the large increase in research on climate impacts and damages in the time since the models underlying the IWG methodology to date were published. The damages module in this draft report relies on three damage functions to synthesize the existing literature. They are:

- *a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2022, Carleton et al. 2022, Rode et al. 2021)),*
- *a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert et al. 2022b)), and*
- *a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).*

Each of the three damage functions is separately estimated in combination with the socioeconomics, climate, and discounting modules. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods. GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE and DSCIM are not included in Howard and Sterner's (2017) final sample of studies. In Section 4.1 of the draft report, EPA combines the multiple lines of evidence on damages by averaging the results across the three damage module specifications to present SC-GHG estimates for a given range of discount rates.

- a. *Does the damages module in this draft report offer a more robust representation of the current body of scientific evidence on climate damages than the damage functions embedded in the three integrated assessment models used in the IWG methodology to date (which relies on the default damage functions in the DICE, PAGE, and FUND integrated assessment models)? Why or why not?*

In short, it is a clear step forward from the prior Interagency Working Group (2015) effort. If Rennert et al. (2022) is any guide here, it may also be the single most important update affecting the final number with the sole exception of assumed discount rates.

At the same time, it may also be the module in need of most work. In particular, a closer look at the decomposition of the three damage modules (see e.g. Table 3.1.4) makes it unclear whether it is more appropriate to average across the three functions or perhaps

even, in part, add them. DSCIM focuses on five sectors or impact categories, GIVE on four, leaving out labor productivity. The sole overlap in sources across the two is Diaz (2016) for sea-level rise damages. It would take quite a bit more work of diving into the specific sources to understand whether it is truly appropriate to average across them, or whether even adding (some of) the now separate damage modules might be more appropriate.

Similarly, the damage function based on the Howard and Sterner (2017) meta-analysis is just that: a by now well-established analysis of several prior published results. It, too, is a clear step forward from the prior Interagency Working Group (2015) effort, yet some of these prior studies, by now, are rather outdated themselves and would deserve a second look. For example, mortality seems to barely figure into the calculation, once again raising the question of whether averaging across damage modules is the appropriate step, rather than adding some damage function components to those from DSCIM and GIVE.

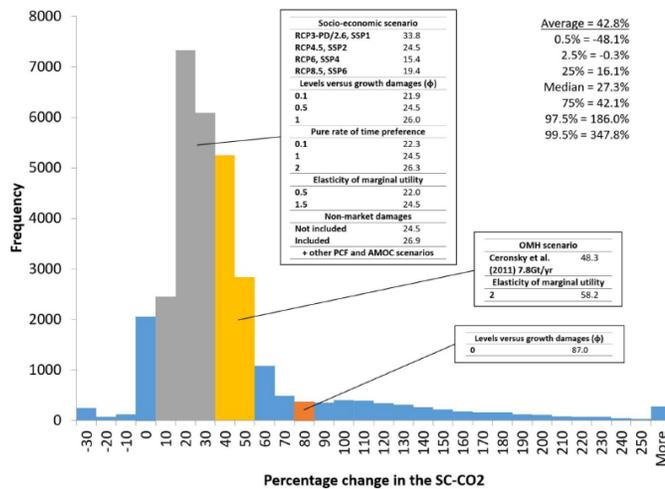
b. Does the draft report’s use of multiple damage functions reflect the breadth of the current scientific literature on damages for this update? If not, what changes to you recommend? Do you think that there is a better approach for this update?

One possible extension (or cross-check) here might be to look at the statistical damage functions presented by the IPCC (2022), in particular the Figure Cross-Working Group Box ECONOMIC.1, panels (a)-(c), p. 16-114.

Another is to explicitly account for climatic tipping points, as in Dietz et al. (2021). Doing so alone would, according to our analysis, increase the SC-CO₂ by between ~27-43%, with a potentially long right tail:

Economic impacts of tipping points in the climate system

Tipping points increase SCC by between ~27-43%, with large, right-skewed distribution



Source: Dietz, Rising, Stoerk & Wagner (PNAS 2021), gwagner.com/tipping-economics

That tail, in turn, leads to roughly a 1 in 10 chance of these eight modeled climatic tipping points more than doubling the SC-CO₂.

We do so here in Figure 3 of Bauer, Proistosescu, and Wagner (2023):

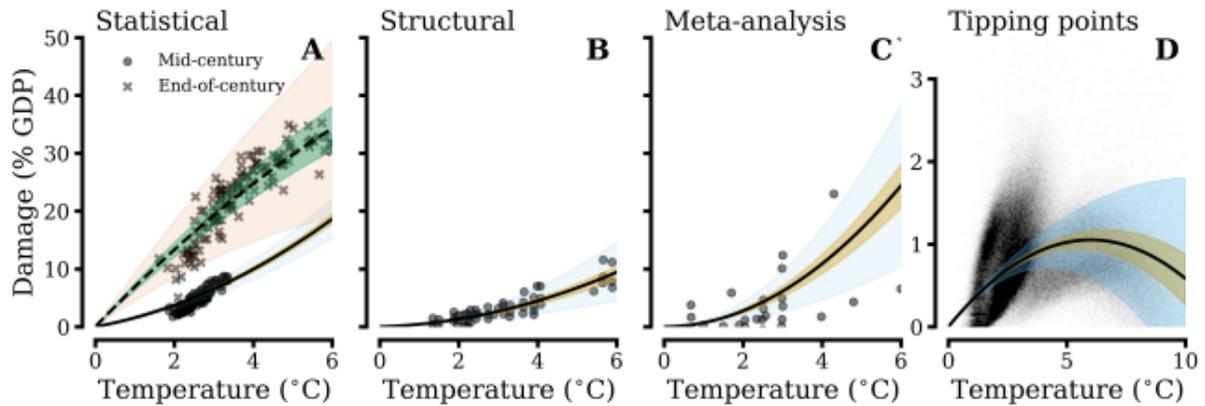


Figure 3: Damage functions. Shown are each of our damage functions by methodology (statistical, structural, and meta-analytic) as well as the marginal damages owing to tipping points. Note the statistical damage function shown assumes SSP2–4.5. In each panel, yellow shows ± 1 standard deviation in the damage function, while the blue shaded region shows ± 2 standard deviations. For the end of century estimates in panel A, the green region shown ± 1 standard deviation and the salmon shows ± 2 standard deviations.

One striking observation: statistical “end-of-century” estimate might reverse the shape of the damage function from concave to convex. All this makes it important to highlight the large differences and resulting uncertainties across different assumed damage modules.

- c. *For the damage categories that are represented, are there additional studies or valuation methodologies that the EPA should consider in modeling these categories in this update? Please describe the advantages of these studies relative to the methods used in the draft report.*

See (b) above around the use of ‘statistical’ damage functions and especially also the tipping points component.

- d. *Are there additional categories of damages that should be considered for inclusion in the individual sectoral damage functions in this update? Please describe the peer reviewed literature that could be used to inform the modeling of these damage categories.*

Arguably the largest omission concerns climatic tipping points a la Dietz et al. (2021).⁸

- e. *Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency of the damage function calibrations or characterization of uncertainty in the draft report?*

Instead of averaging across damage functions, a key improvement seems to be

⁸Full disclosure: I am among the “et al”s.

distinguishing between parametric uncertainty within any one damage function on the one hand, and structural uncertainty across different damage functions. In Bauer, Proistosescu, and Wagner (2023), for example, we explicitly account for both types of uncertainties. We make no judgment call over which damage function is more appropriate, nor do we average across them. We instead “assign a hyper-parameter in our simulated climate damages that randomly chooses a damage function,” allowing us “to remain agnostic with respect to which damage function we choose.” I would counsel a similar approach here.

Meanwhile, at the very least, this module points once again to the appropriateness of calling the resulting SC-CO₂ a “partial” estimate, given that any of the individual damage functions used only account for some of the known climate impacts.

f. Do you have longer-term recommendations for improvements to this module in future updates?

Updating the damage function is among the most challenging tasks. The most important: arrive at a clear process to continuously update the damage function module with the latest scientific estimates (see section 1d above).

6. Discounting module

The discounting module used in the draft report relies on a set of calibrated dynamic discount rates. These rates were developed using a Ramsey discounting approach that endogenously connects the discount rate and socioeconomic scenarios where the Ramsey formula parameters are empirically calibrated to match near-term consumption interest rates and reconcile long-run interest rate behavior and economic growth uncertainty consistent with the RFF-SPs. Uncertainty in the starting rate is addressed by using three near-term target rates – 1.5, 2.0, and 2.5% - based on multiple lines of evidence on observed interest rate data.

a. Does the discounting module in this draft report adopt an approach that allows the discount rate to better reflect recent quantitative evidence on the consumption rate of interest and capture the long-term relationship between discount rates and economic growth relative to the discounting approach used in the IWG methodology to date (which relies on three constant, exponential discount rates)? Why or why not?

Discounting has the single largest impact on the SC-CO₂. The discounting module applied in the EPA report appropriately represents the biggest advance from the prior SC-CO₂ efforts. It is based on Newell, Pizer, and Prest (2022), which drives a relatively simple yet well-founded “discounting rule” for the SC-CO₂.

The arguments for using a 2% ‘central’ estimate and values of 1.5% and 2.5% around it, in turn, are well-founded in economic theory and in recent advances in empirical understanding (e.g. Drupp et al. 2018; Council of Economic Advisors 2017; Greenstone and Stock 2021; Wagner et al. 2021). In fact, as I mention above, the proposed update to Circular A-4 argues convincingly for an even lower discount rate of 1.7% to be used in

the short term (U.S. Office of Management and Budget (OMB) 2023). This might well argue for an even lower ‘central’ estimate than the current 2%.

b. Are there discounting approaches other than Ramsey discounting that the EPA should consider for this update? Please describe the advantages of these approaches.

No. Ramsey discounting is the appropriate methodology here. As I mentioned in (1c) above, and as alluded to in the document, there are alternative approaches to Ramsey discounting, in particular use of Epstein-Zin utility functions (Epstein and Zin 1989; 1991; Weil 1990). This literature is worthy of further exploration, though despite important contributions to date (Lemoine and Rudik 2017), and my own participation in this literature (Daniel, Litterman, and Wagner 2018; 2019; Bauer, Proistosescu, and Wagner 2023), I do not believe that work on Epstein-Zin-style utility functions are ripe to supplant standard Ramsey discounting approaches in calculating the formal U.S. SC-CO₂.

c. Are there other descriptive approaches for calibrating the Ramsey parameters that the EPA should consider for this update? Please describe the advantages of these approaches relative to the methods used in the draft report.

n/a.

d. Is the discounting module described clearly in the draft report? Do you have recommendations for strengthening the presentation of this module, e.g., with respect to increasing transparency or characterization of uncertainty in the draft report?

Yes, and no. This module might be the most challenging to get right, and the EPA report does a great job of explaining the intricacies in plain language. The discounting module is clearly written, and deserves wide circulation on its own as a standard entry into this literature.

e. Do you have longer term recommendations for improvements to this module in future updates?

The key bit for longer-term updates, here as elsewhere, is around setting up the appropriate process to help identify conditions under which the discount rates used here might be updated. One such example is our improved understanding of the appropriate “climate beta” (Dietz, Gollier, and Kessler 2018; Lemoine 2021), which may well merit updates to the discounting module in the future.

6. Other

a. Accounting for risk aversion:

i. Does the methodology in the draft report more explicitly reflect existing evidence on individuals’ preferences over risks in the valuation of climate damages than the IWG methodology to date (which maintained an assumption of risk neutrality

throughout the analysis and indirectly incorporated risk aversion through exogenous adjustments to the discount rate and through consideration of a fourth value reflecting the 95th percentile of the SC-GHG results under a 3% discount rate)? Why or why not?

The treatment of risk aversion poses the largest challenge to the standard Ramsey discounting framework and all but calls for using Epstein-Zin-style preferences. I do not, however, believe that literature is ripe for incorporating here (see 5b above).

- ii. Are there other parameterizations/approaches that have been applied in the empirical literature that the EPA should consider for incorporating risk aversion in this update? Please describe the advantages of these approaches relative to the methods used in the draft report.***

One important addition is adding at least one scenario/model run that explicitly factors in “equity weights” (e.g. Anthoff and Emmerling 2018). This is especially appropriate given the theoretical problems with using the EPA report’s Purchasing Power Parity (PPP) adjustment of the estimate of a Value of a Statistical Life (VSL) and claims around the application of the Kaldor-Hicks criterion (see 6bi below).

- iii. Do you have recommendations for strengthening the presentation of this modeling decision in the draft report, e.g., with respect to increasing transparency of the parameterization and implementation with the damage functions used in this update?***

[n/a]

- iv. Do you have longer run recommendations for improved ways to account for risk aversion in future updates?***

Include Epstein-Zin preferences, potentially as a scenario/model run, much like factoring in equity weights (see 5b above.) Doing so will allow for an explicit exploration of higher—and perhaps more appropriate—risk-aversion parameters than are currently used.

- b. Characterization of distributional impacts and other presentational recommendations for the draft report:***

- i. Given the spatial resolution available in the modeling performed for this update, do you have recommendations for ways to provide a more robust characterization of the distributional impacts of climate change in the draft report?***

One key assumption behind the distributional impacts of climate change is the EPA report’s PPP-adjustment of the estimate of a Value of a Statistical Life (VSL). While this application seems appropriate at first glance, it is theoretically and practically inconsistent with a strict interpretation of the Kaldor-Hicks criterion (Bressler and Heal 2022). Furthermore, doing so departs from OMB’s previous guidance “for

treating equally persons of different income levels at a given time, for the purposes of valuation” (National Academy of Sciences 2017, 183). A full reconciliation of theory and practice would be difficult. I would, thus, counsel to treat the PPP-adjusted estimates as one possible scenario and also present a scenario that explicitly includes equity weights, while removing the erroneous “Kaldor-Hicks” justification for using PPP-adjusted VSL estimates.³

- ii. *Do you have recommendations for strengthening the presentation and discussion in the draft report regarding what constitutes damages to U.S. populations in the case of a global pollutant that could have international implications that impact the United States? Is the reporting of damages occurring within U.S. borders based on current modeling capabilities in GIVE and DSCIM described transparently in the draft report? If not, do you have recommendations for how this presentation and discussion could be strengthened?***

The EPA report should explicitly discuss the importance of equity weights in calculating the SC-CO₂ relative to the current practice of PPP-adjusted VSL figures.

- iii. *Do you have recommendations for strengthening the presentation and discussion of other topics in the draft report?***

My biggest direct criticism of the writing and presentation of the EPA report concerns its treatment of risks and uncertainties.

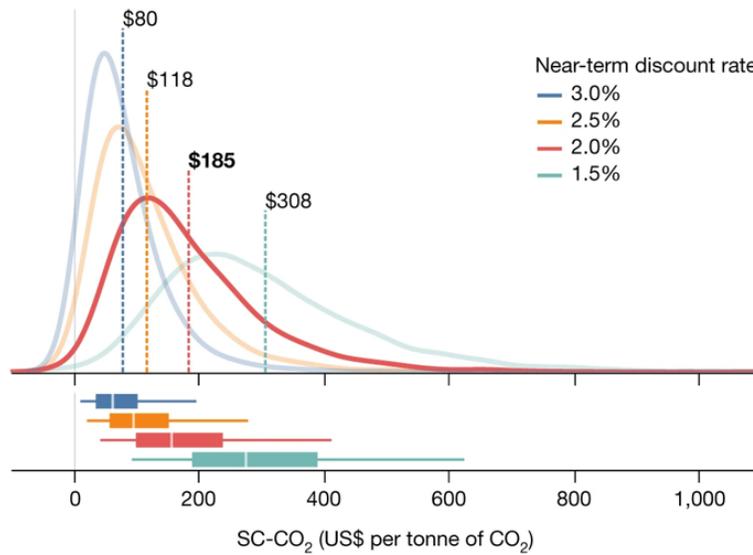
While the report itself goes into detail on the generally impressive effort to model climatic and climate-economic risks and uncertainties, Table ES.1 in the Executive Summary, arguably the most important table of the entire document, appears to take a step backwards in presenting these risks and uncertainties. The prior Obama-era effort presented three columns for the SC-CO₂: three different discount rates, plus the 95th percentile of the distribution for the ‘central’ discount rate (U.S. Government Interagency Working Group on Social Cost of Carbon 2015). While most readers of the report still zeroed in on the ‘central’ ~\$50 value, the table clearly showed the importance of considering the tail of the SC-CO₂ distribution.

The current presentation in the Executive Summary and in Table ES.1 appropriately rounds the numbers to avoid false precision, but it does not present the potentially long right tail of the SC-CO₂. Figure 3.1.1 does so on page 69 of the draft. Finding a way to represent this range in the Executive Summary is crucial, and it might well be best accomplished by putting the same figure in the ES.

Doing so might involve modifying Figure 3.1.1 to represent the full distribution of possible values, akin to Figure 2 in Rennert et al (2022):

~\$185 Social Cost of CO₂

Based on 2% constant discount rate, with potentially long right tail



Source: Rennert et al. "Comprehensive Evidence Implies a Higher Social Cost of CO₂" (Nature, September 2022).

- c. *Do you have longer term recommendations, in addition to any discussed in the subparts above, for potential methodological improvements that warrant consideration in future updates of the SC-GHG estimates (e.g., estimation approaches for improved accounting of interactions and feedback effects within and between modules, valuation of climate change impacts (e.g., estimating willingness-to-pay for mortality risk changes), characterization of climate damages to U.S. populations and various subpopulations (e.g., environmental justice communities))?*

My largest long-term comment concerns the treatments of risk aversion and equity weights, reflected in (6a) and (6b) above, respectively. The EPA report appropriately strives to base the SC-CO₂ in the long-standing application of the Kaldor-Hicks potential compensation criterion. Equity weights within and across countries might lead to a more direct and, thus, appropriate consideration of differing impacts of climate change. Appropriately applying equity weights, in turn, could be based on one of two methods: calibrating based on observed behavior of how averse to inequality society is, or based on ethical views of how adverse to inequality society should be (Wagner et al. 2021). Picking the ‘correct’ equity weights, thus, mirrors the process of picking the correct discount rates, and doing so will be no less important to the resulting SC-CO₂. Something similar goes for risk aversion.

III. SPECIFIC OBSERVATIONS

Page	Paragraph	Comments or Questions
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